THE IMPACT OF CHANGE ORDERS ON MECHANICAL CONSTRUCTION LABOR EFFICIENCY

by

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"The fear of the Lord is the beginning of knowledge,

but fools despise wisdom and instruction."

Solomon, Proverbs 1:7

To Lori and Jonah for their love and inspiration.

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ABSTRACT

Change orders impact many areas of construction projects. However, the impacts that change orders have on labor efficiency are much harder to quantify and are, therefore, a significant risk to contractors. Little research has been completed in the past quantifying these impacts so that disputes are common between owners and contractors regarding the actual cost of change. This study uses data from 43 projects, 27 impacted by changes and 16 not impacted by changes, to develop a linear regression model that predicts the impact on labor efficiency. The input factors needed for the model are: (1) Total Actual Project Hours, (2) Total Estimated Change Hours, (3) Impact Classification, and (4) Timing of Change. Timing of Change is calculated by breaking the project schedule down into six periods (i.e., changes before construction start, 0 - 20%, 20 - 40%, 40 - 60%, 60 - 80%, and 80 - 100%), listing the percentage of change that occurred in each period, and calculating a weighted timing factor. The model calculates the labor loss or gain in efficiency for a particular project so that owners and contractors will better understand the true change impact on labor efficiency. Significant results have been found in hypothesis testing. The results show that impacted projects have larger amounts of change, have a larger decrease in labor efficiency, and are more impacted by change that occurs later in the project schedule. These results appear to be consistent with the intuitive judgement of industry professionals. The research is limited to the mechanical trade, but does include specific work in plumbing, HVAC, process piping, and fire protection.

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

The construction industry in the United States is filled with numerous risks for contractors, designers, and owners. In order to remain viable in the business world, the contractor, designer, and owner must minimize the risk to themselves. To start with, risk should be allocated to the party that can most easily manage it. One such area of risk includes change orders.

An owner's continually changing needs coupled with design problems can create a project with a significant number of change orders. These changes can have significant effect on the original project and cause problems in such areas as material procurement, project management, scheduling, trade conflicts, rework, and decrease in labor efficiency. The proper management of change orders will help ensure a profitable contract for the contractor, reduce the overall costs to the owner, and reduce disputes between the two.

Although many factors are involved in the proper execution of change orders, this thesis will focus on the impacts that change orders have on labor efficiency. Labor is the one dominant risk in change because the materials, equipment, management, and overhead are typically less variable in terms of cost. Typically, labor costs amount to between 25% and 50% of the total mechanical construction cost. The average labor cost for the projects used in this research was 34.5%. On the other hand, labor efficiency can vary widely from job to job and from the number and timing of project changes.

1.2 Background

The mechanical construction industry in the United States accounts for a significant portion of a $605 billion and 5 million worker construction industry (U.S. Census 1992). With advances in technology, mechanical contractors have continually become more sophisticated and the work they perform has become increasingly complicated.

Mechanical construction is one of the "connected trades." A "connected trade" means that project systems are interconnected and that a change in one portion may cause changes throughout the project. For example, a change in the number of floors in a building will increase the HVAC requirements causing changes in the air handling units and the sizes of ductwork in order to meet the air requirements and balance the system. Therefore, mechanical contractors can be most severely affected by change as their project planning must be completely revised and their labor efficiency declines.

Labor efficiency can be impacted by more than change orders on a job. Weather, management, material delivery, proper equipment, overtime, stacked trades, tools, crew make-up, and jobsite conditions can all affect how efficiently a given crew performs. These factors must be considered in the overall project performance because they will also determine the profitability of a contractor on the jobsite. However, due to the complexity of construction projects, only the impacts of change orders on labor efficiency will be the discussed in this thesis.

1.3 Definitions

Change as defined by Webster is "to give a different position, course or direction" and order means "to give a command" (Webster 1986). In the construction industry, a change order can be defined as "written authorization provided to a contractor approving a change from the original plans, specifications, or other contract documents, as well as a change in the cost (R.S. Means 1991). In this research a change order is a modification written after the signing of the construction contract. Therefore, some of the change orders occur before construction commences. Contractually speaking (Coffman 1996), "A change order states the agreement of the parties to:

-an addition, deletion, or revision in the work;

-an adjustment in the contract sum, if any;

-or an adjustment in the contract time, if any."

Impact is defined as "the force of impression of one thing on another" (Webster 1986). In construction, change orders can impact other portions of the work. One can reasonably argue that every change order impacts the remainder of the project to some degree. However, for the purposes of this research, some projects have changes that do not negatively affect the remainder of the job so that they are said to have "no impact." Whether or not the project was impacted by change was a judgement call made by the experienced project management staff for each particular project submitted.

Efficiency: a Macro Analysis

Efficiency is defined as "effective operation as measured by a comparison of production with cost" (Webster 1986). Labor efficiency is used in this thesis only in the aspect to which change orders increase or decrease the number of hours to perform the base or original contract. In this research the available information on labor hours includes: originally estimated labor hours, total expended labor hours, and estimated change order hours. Originally estimated labor hours is the amount of direct labor hours estimated by the contractor on the base project before construction begins and before any changes occur. Total expended labor hours is the amount of direct labor hours that the contractor expended to complete the entire job, both base and change. Estimated change order hours is the sum of direct labor hours expected to be needed by the contractor to complete all changes. The base project labor hours is the amount of labor hours expended by the contractor to complete the original contract work and is the difference between the total expended labor hours and the estimated change order hours. The variable that will be used to determine labor efficiency is called "Delta". Delta ("Δ") is the difference between base project labor hours and the original estimate of project labor hours. If the contractor completes the base work more efficiently than originally estimated, delta will be negative. On the other hand, if the contractor completes the work less efficiently than originally planned, delta will be positive. Figure 1.1 describes in labor hours the relationship between the original estimate, base, estimated change order, and delta.

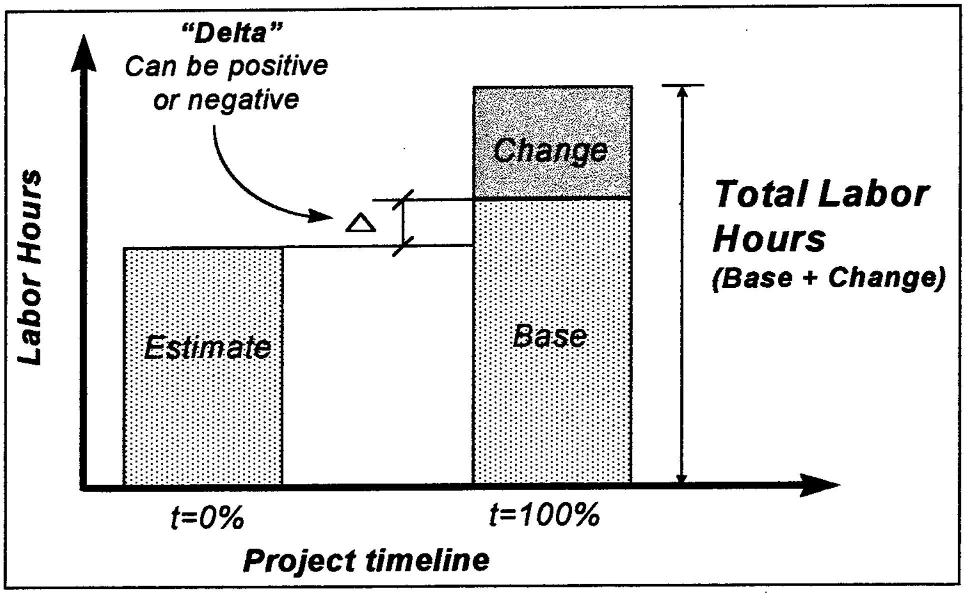

Figure 1.1 - Illustration of "Delta" (Thomack 1996)

1.4 Problem Statement

The construction industry has been plagued in the past by large numbers of disputes resulting from change orders. Since it is the owner's right to make changes and the contractor's right to receive fair and equitable adjustment for all work performed, improvements need to be made to the methods by which fair and equitable adjustment is made. Owner's do not fully understand the impacts that their changes bring to contractors and many times feel that contractors are placing inflated claims before them. Contractors, meanwhile, are trying to cover their costs so that they can remain competitive and profitable.

1.5 Research Objectives

The main research objective is to develop a model to estimate a reasonable value for the impact that change orders have on labor efficiency. Owners and contractors will both benefit from the model by developing a better understanding of what the actual labor costs are on a project impacted by change.

A second objective is to attempt to relate projects impacted by change with the experience level of the project management staff.

A third objective is to show a reasonable relationship between projects impacted by change and the timing of the change orders themselves.

In many ways, each construction project is unique and must be planned and executed with each detail taken into account. Numerous trade contractors are involved in large projects so that making close comparisons between projects becomes difficult. Because each project is different, only the mechanical trades portion of construction projects was used to limit the variation and produce a more comparable data set. When change orders occur, a contractor often must make corrections to the initial plan and coordinate with other trades to ensure smooth execution. This research takes a "macro" level approach and attempts to study change order impacts on labor efficiency from a total cost perspective and relate projects impacted by change to the "delta" value. An attempt is also made to relate whether a job was impacted by change and the timing at which the change orders occurred.

1.6 Research Methodology

The following steps were taken in the study of change orders:

- Conduct Literature Review;
- Collect Initial Data Set;
- Analyze Initial Data Set;
- Formulate Data Collection Tool;
- Contractor Evaluation of Data Collection Tool;
- Contact Interested Mechanical Contractors;
- Distribute Data Collection Tool;
- Collect Project Data;
- Review and Clarify Project Data;
- Analyze Data;
- Develop Impact Model; and,
- Summarize Conclusions and Recommendations.

The initial literature review was conducted to find completed studies on related work so that this research would add to and complement our knowledge base and not simply repeat it. However, this study is done with the same general outline as the study completed by Thomack (1996).

The initial data collection used project input from two mechanical contractors to show what information was readily available in contractor accounting procedures and could be used in the

study. The project data were analyzed to develop a Data Collection Tool that is found in Appendix A. After the Data Collection Tool was drafted, it was distributed to four contractors for their review and comment. In this way, a more accurate questionnaire was ensured by the author. This questionnaire was then distributed to contractors that showed interest through their respective organizations – Mechanical Contractors Association of America (MCAA) or The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA).

When the contractors returned the questionnaires, the project information was reviewed. To ensure quality data, follow-up calls were necessary for clarification and then the data were entered into the database. The data were then analyzed to check if the hypotheses could be supported and to develop an impact model. This procedure is explained in Chapter 4. Finally, the results, conclusions, and recommendations are given.

1.7 Research Scope

This research encompasses only mechanical trades on construction projects. Forty-three projects from fourteen contractors in nine different states are used. The contractors are members of the Mechanical Contractors Association of America (MCAA) or the Sheetmetal and Air Conditioning Contractors' National Association (SMACNA) or both. The mechanical portion of the projects range in size from $93,000 to $11,686,000 and from 1,050 to 163,000 total labor hours. Although there are many impacts caused by change, the focus is on the direct impact of change orders on labor efficiency. Other study included relating impact to

timing of the change orders and schedule increase and relating impact to project manager experience using years in the industry, years with the company, number of projects of the same type, and number of projects of similar size.

1.8 Research Assumptions

Two major assumptions are made regarding this study. They are:

1. The original project estimate is reasonably accurate.
2. The change order estimates are accurate.

The first assumption is made based on three factors. First, all participating contractors have been in the business for many years and thus have been successful. Second, the construction industry is very competitive so that estimates and bids must be accurate in order to obtain work and still make a profit. Third, all of the contractors have sophisticated enough accounting systems that they can monitor costs and provide accurate estimates. This assumption is essential, since The Total Cost Method is used in the analysis. The Total Cost Method will be described in Chapter Two.

The second assumption is based on the fact that almost 70% of the projects did not have actual change order numbers. This is primarily because of the difficulty in tracking change orders and their impacts and because of the cost to the companies in overhead to track each change separately from the job. Using the estimated change order data also assumes that the owner is knowledgeable enough to keep the costs in a reasonable range. None of the

projects, from a statistical point of view, indicated that contractors took advantage of the owners by inflating charges beyond the normal industry standards.

1.9 Organization of Thesis

The thesis is arranged generally in the same fashion as the research itself. Chapter 1's introduction will be followed by a literature review in Chapter 2. Chapter 3 will explain the data collection process and characterize the collected data. Chapter 4 will be the largest portion of the thesis and will present the thesis hypotheses, the analysis used and the results achieved. Chapter 5 will present two tools for contractors to use in managing change while Chapter 6 will summarize the thesis, give recommendations, and state conclusions. The data collection tools used, an explanation of the statistical tests, a suggested data collection tool for future study, and a list of possible impacts of change orders on labor efficiency are included in the appendices.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Although much has been written about change orders and their effects on contractors, very little documentation exists to quantify change impacts on labor efficiency. This chapter focuses on the materials that do exist. Summaries of key points from selected documents will be presented and explained in relation to this thesis. Discussions on management of change, pricing of change orders, impacts on productivity, and timing of change will follow.

2.2 Management of Change Orders

The management of change orders can mean survival or failure to a contractor. Therefore, it is essential that contractors establish company procedures for handling change orders. "Few items in a project manager's or cost engineer's busy schedule cause disproportionately more work and anxiety than do change orders. Because of their nature, they are often perceived to reflect flaws in the planning, design, or execution of the project. They almost always increase the capital cost of the project; they also result in a heavy administrative load because they require much review, discussion, and tracking" (Ehrenreich-Hansen 1994).

Ehrenreich-Hansen goes on to say, "Change orders are a necessary and useful tool in the management and cost control of construction projects." Almost every construction job has change and the contractors that are prepared to handle it will prosper. By effectively implementing early change order planning, projects can be completed within the budget and time allocated.

Ehrenreich-Hansen gives reasons for change as design developments, scope changes, site conditions, owner delays, code changes, and abnormal weather conditions. In order to effectively handle changes, change order management must start early in a project. In many cases, optimum management is done through planning that includes the project objective, scope of work time plan, risk plan, cost plan, management plan, and controls plan.

There are a number of publications that help in the management of change orders. The U.S. Army Corps of Engineers published the *Modification Impact Evaluation Guide* in 1979 to help its contracting officers more effectively deal with change and particularly the impacts on the original scope of work. MCAA's *Change Orders, Overtime, Productivity* guide provides guidance and checklists for handling of change orders. Also forms are included for estimating change costs. Impact on productivity is mentioned and a list of possible impacts is given. However, no method of calculating cost of impact is given.

SMACNA's publication entitled *Change Orders* gives guidance to the handling of change orders. Assessing risk, pricing changes, and presenting changes are all covered. Change order administrative forms are included.

Succeeding at Contract Changes and Claims published by the American Subcontractors Association (ASA) is intended to guide contractors through all aspects of handling change orders. First, it discusses contract formation and change clauses and their legal basis. Second, it presents guidelines on effective change management and administration. Third, it

discusses change order pricing and time extensions. Finally, it advises contractors on how to prepare and present change proposals and claims.

2.3 Pricing of Change Orders

Owners often believe contractors use change orders to collect additional compensation for either an inappropriate bid or a poor field performance. Some even argue that a prudent contractor should include a contingency for processing them and a factor for loss of productivity at bid time. While most contractors agree that change orders are unavoidable, few feel they are contractually obligated to include such contingencies. Under a competitive bidding system, any contractor who did so would not be the low bidder.

Contractors reject this notion that they bid jobs low to make up the difference in change orders. In fact most claim that they prefer to have no changes since their efficiency is better, their administrative burden less, and they make more money by getting in, doing the job, and getting out (Sarvi 1992).

Many disputes between owner and contractor arise during the negotiations regarding the price for the change. Owners must recognize that change orders can impact productivity and job schedules, and that the true cost of a change order can be significantly greater than the cost of labor, materials, equipment, and markups. Most contractors feel that their greatest risk is related to labor because of the impacts of the change.

ASA divides pricing of change orders into four major categories: (1) direct costs, (2) indirect costs, (3) impact costs, and (4) miscellaneous costs. Direct costs include labor, materials, subcontractors, and equipment. Indirect costs include field and main office overhead. Impact costs are calculated using Direct Cost Pricing, Modified Total Cost Method, Partial Total Cost Method, or Total Cost Method.

Direct Cost Pricing or Differential Cost Calculation begins by establishing unimpacted labor productivity "normal" rates during non-impacted portions of the project. Then the actual productivity rates are determined while the project was impacted. Next, the determined efficiency factor is applied to that portion of the changed work. This includes adding impact costs to overhead. However, this method is very time consuming and most contractors do not keep the necessary records to determine the "normal" productivity rates and especially not for each of the separate types of work as required. Because of this, the Total Cost Method or its derivatives are used.

The second is the Modified Total Cost Approach. This method calculates normal productivity based on the original estimate for the project. To determine the proper estimate, the contractor's estimate is compared to the next three highest bids when the difference is less than 3 - 5%. The normal amount of hours is taken as the contractor's estimated multiplied by a ratio of the average of the next three bids. If the difference is more than 5%, the contractor's estimate is compared to a theoretical estimate based on published estimating tables. When this theoretical estimate is no greater than 3 - 5% more than the contractor's

estimate, the theoretical estimate is taken as normal. Any labor amount over the "normal" amount is taken as impacted.

The third method is the Partial Total Cost Method. This method is used when only certain aspects of the work are affected by the change. The remainder of the job is neglected and "normal" hours are determined for the affected portion only. This requires a cost control system that permits extraction of the estimated and actual costs for only those particular portions of work.

The fourth method is the Total Cost Approach. When the contractor's estimate is reasonable and alternative methods are not possible, the contractor's estimate is assumed to be "normal" (Moselhi et al. 1990). The calculations in this thesis are based on the Total Cost Method since no other data were available.

All four of these methods try to calculate impact after the project work is completed. Another new method called Forward Pricing (Kasen and Oblas 1996) was used during the construction of a \$468 million wastewater treatment plant in Seattle. Partnering was used on the project and a change order pricing system was established at the beginning to deal with changes in order to keep the work going, reduce ultimate costs, and eliminate disputes.

The pricing system used Equation (2.1):

$$\mathbf{Impact} = \mathbf{D} \times (\mathbf{T+C+F}) \times \mathbf{M_v} \times \mathbf{M_n} \qquad \textbf{(2.1)}$$

where, **D** is the sum of all direct costs that have impacts.

T is timeliness, representing the time between notice to proceed and the actual schedule activity start date of the change. This factor receives full impact value for changes with short notice and no impact for those with long notice. Periods between short and long follow a graduated scale.

C is complexity of the disciplines involved. Civil, architectural, electrical, and mechanical disciplines each have an equal distribution of factors. Participation of each discipline is determined by direct cost breakdown.

F is the future factor, the future impact dealing directly with the timing of the change and the current schedule float. Like timeliness, this factor receives full impact value for changes with little float and no impact for those with large float. Periods between little and large follow a graduated scale.

$\mathbf{M_V}$ is the cumulative value multiplier, the total value of changes that actually have impact. This factor is only applied when the cumulative dollar value of changes having impact reaches a minimum value of 2% of the base contract. It reaches its maximum value when impact changes amount to at least 11% of the contract value.

$\mathbf{M_n}$ is the cumulative number multiplier, the number of changes that actually have impact on the contract.

All of these factors are negotiated at the beginning of the contract, but are subject to future negotiation if one of the parties desires. This forward pricing system worked well for this project, but it must be tailored in order to be applied to other construction projects and a good working relationship with a win-win attitude is essential. Although each of the variables used in the equation seems appropriate, the paper fails to properly explain how the formula was developed.

This thesis attempts to use past projects to develop a predictive model that can be used to estimate the impact of change on labor efficiency.

2.4 Impact on Labor Productivity

Contractors are impacted by change orders, primarily on labor productivity. Therefore, a number of publications address both the qualitative and quantitative impacts. The first publication reviewed was the *Modification Impact Evaluation Guide* (Army Corps of Engineers 1979). This publication establishes guidelines on identification and evaluation of that portion of the fixed-price construction contract modification defined as "impact on the unchanged work."

Along with giving contracting officers general guidance on the handling of change orders, it provides charts to estimate impact when dealing with acceleration, crew overloading, stacking of trades, longer work days, and longer work weeks. The charts are developed from experience and not from any referenced quantitative research.

Change order guides by MCAA, SMACNA, and ASA all give good lists of possible impacts produced by change. Only ASA addresses the quantitative aspect of determining the actual impact on labor efficiency and uses the methods recorded in the previous section to do so.

"The Effect of Change Orders on Productivity" (Leonard 1987) introduces the results of an extensive statistical analysis completed on 57 projects. It looked at the relationship between productivity loss and change orders. The analysis was divided between electrical/mechanical and civil/architectural construction.

Productivity loss was due to: loss in productive job rhythm, demotivation of work force, unbalanced crews, excessive fluctuations in manpower levels, lack of engineering and management support, and acceleration. Productivity losses resulting from change orders were experienced mainly during later periods of the job when the majority of change order work was carried out and when the delayed or disrupted activities were being completed.

Regression techniques were used to analyze the loss in productivity. The results indicate a significant direct correlation between percentage loss of productivity and percentage change.

When change was the only major cause of productivity loss, the analysis yielded coefficients of correlation of 0.88 and 0.82 for electrical/mechanical and civil/architectural construction respectively. The correlation coefficients decreased as other factors affecting productivity were taken into account.

The developed models are used when the range of change as a percentage of actual contracted hours is between 10 and 60%. Separate models are given for electrical/mechanical and civil/architectural construction but generally show that as the percentage of change increases, the percentage of productivity loss increases as shown in Figures 2.1 and 2.2.

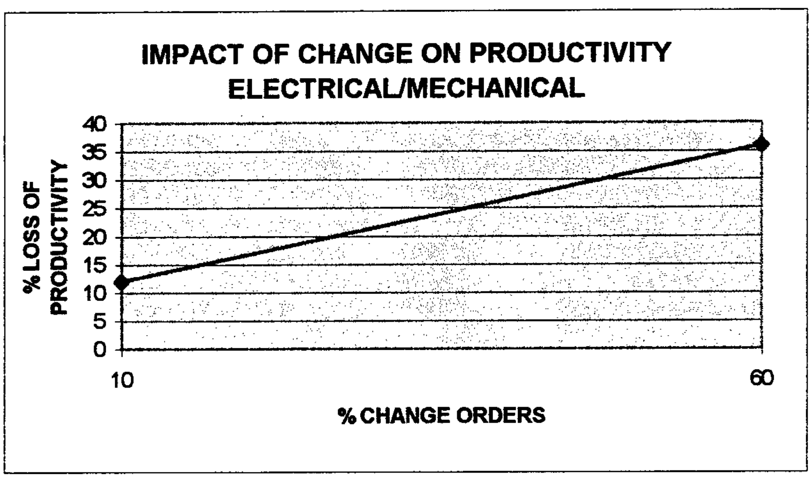

Figure 2.1 - Impact of Change on Labor Productivity

for Electrical/Mechanical Construction (Leonard 1987)

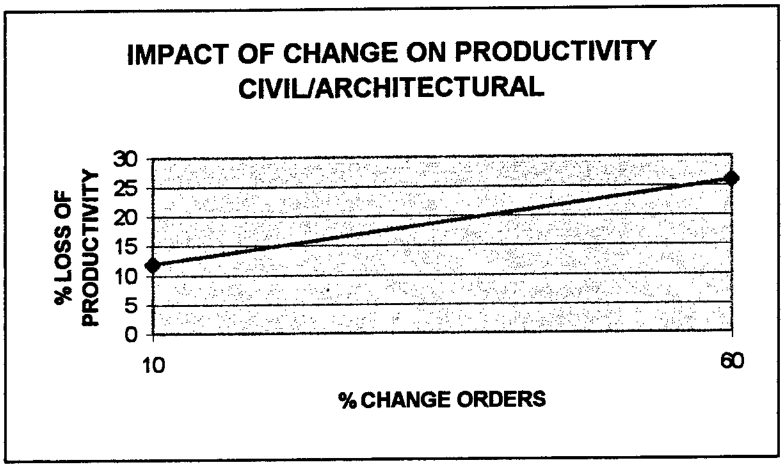

Figure 2.2 - Impact of Change on Labor Productivity

for Civil/Architectural Construction (Leonard 1987)

This study developed the simple linear models listed in Figures 2.1 and 2.2. The models take into account a wide range of construction projects so that their simplicity leaves them suspect. The analyses performed for this research does not support Leonard's models even though this research was done using only mechanical construction data.

In a continuation of the previous study (Leonard 1987), the same project data was used and further analyzed (Moselhi et al. 1990). Here the impact of change orders on productivity is examined quantitatively. The impact costs are not the direct costs of performing the changes or extra work, but rather the additional costs incurred in performing the work affected by delays and disruptions resulting from the changes. The article tries to provide an overall awareness of the impacts that change orders have on productivity. Models that depict the relationships between change orders and productivity losses under certain conditions are presented as useful tools for quantifying the impacts of change. Loss of productivity is

defined as "the decline in labour efficiency due to specific causes from the level which could have been achieved except for the cause(s) under examination." Thus the loss of productivity expressed in labor hours is the difference between the hours actually spent and the hours that "should have been" required.

The study further quantifies the impact of the effects of other major causes of loss of productivity. Some of these include: acceleration and inadequate scheduling and coordination. Three ways are used to calculate impact cost: Differential Cost Calculation, Modified Total Cost Approach, and Total Cost Approach. These methods are describe in the previous section.

The studies conclusions include:

(1) Total labor hours expended on change orders expressed as a percentage of total hours directly correlates with percentage loss of productivity. Relationships between change orders and loss of productivity are best described by linear rather than nonlinear models, and the correlations are relatively strong.

(2) When work is delayed and disrupted by change, productivity losses can be estimated with models as shown in Figures 2.1 and 2.2.

(3) Productivity losses are affected by the type of work. At the same level of change orders, productivity losses are higher for electrical and mechanical work than for civil and architectural work and the difference increases as the level of change orders increases.

(4) Additional major causes of productivity-related impact have a cumulative negative effect on productivity.

The simple models developed in this study do not take into account other variables related to change order impact. For instance, the study does not consider timing of change, management experience, size of the job, or even projects not impacted by change in the analysis. Therefore, the models given appear to be too simple for the construction industry since each project is unique.

Another study (Thomas and Napolitan 1995) details the effects of change orders on labor productivity using multiple analyses on 522 workdays of data on three industrial projects. The data base included statistics taken on disruptions to labor as caused by change and other factors including rework, weather, length of the workday, and other disruptions. The analysis showed that labor was only 71% as productive when change orders occurred. The analysis was based on a performance ratio (PR) that was equal to Actual Productivity divided by Baseline Productivity. Baseline productivity was calculated on the days that no change, rework or bad weather affected production. The significance between PR and the presence of change was $\alpha = 0.086$ which shows a significant relationship. The closer to zero the more significant the relationship.

Next, a multivariant regression model was developed and is shown as Equation 2.2:

$$\mathbf{PR = 2.57 + 1.07 \times Changes\ Indicator} \qquad \mathbf{(2.2)}$$

The changes indicator is either one (1) if change is present or zero (0) if it is not. Therefore, PR = 3.64 if change is present and 2.57 if it is not giving an efficiency of 0.71% (2.57/3.64) when change impacted the job. This shows a loss of efficiency of about 30%.

This study has two major problems. First, the number of projects used is very small (3) so that no statistically significant conclusions can be made. Second, the R^2 value was not reported for the model and is believed to be small.

A Construction Industry Institute study (CII 1995) summarizes research done by CII Change Management Research Team on the quantitative impacts of change. The research includes 104 projects from 35 contractors. Two basic relationships were studied:

(1) The more change experienced on a project, the greater the negative impact on productivity.

(2) Changes that occur late in a project are implemented less efficiently than changes that occur early in the project.

A pilot test was performed and demonstrated that productivity information could not be gathered on a monthly basis, but only on a cumulative, end-of-project basis because companies do not retain their change related data on a periodic basis.

The study concludes that:

(1) There is a definite downward trend in productivity as the percent change increases, and no projects with greater than 25% change experienced productivity better than planned.

(2) Timing of change and its effects could not be proven in the study. The study used material cost and project cost by month to try and support their hypothesis.

(3) Results indicated that impacts negatively affected productivity once change exceeded 5% of the project.

The analysis conducted with this research found the opposite to be true of conclusion (1). There was no definite downward trend in labor efficiency as the percent change increased which may be best explained by the idea that contractors actually estimated more hours into the changed work than were actually performed.

One other recent CII study (Ibbs and Allen 1995) attempts to quantify the impacts of project change. Three hypotheses studied were: (1) Changes that occur late in the project are implemented less efficiently than those implemented early on, (2) More project change brings more negative impact on labor productivity, and (3) The Cumulative Change Effect increases proportionately to the amount of change on a project. Hypothesis (1) is covered in the next section. Results for hypothesis (2) showed that labor productivity is negatively affected once change orders grow to over 5% of the project. The continued decrease in productivity is attributed to the "ripple" effect which states that a change on one trade may impact other

trades on the same project. The regression analysis gave poor R square values and no statistically significant results were concluded.

2.5 Timing of Change

As stated by an industry professional (Coffman 1996), "When evaluating change orders, regardless of their cause, the most significant factor is when the change occurs." Experienced construction professionals understand this fact to be true. However, why is so little quantitative information available on change order timing and its impact on labor efficiency? The answer may be that contractors do not record change order information to the degree necessary to analyze the timing of change and its effects properly.

A few sources attempted to address the issue of timing. As noted above, CII attempted to quantify the impacts using total and material costs, but did not receive significant results (CII 1995). In fact, only 19% of the projects surveyed had any information to be analyzed. Another study (Thomas and Napolitan 1995) suggests that the key factor affecting labor efficiency is the timing of the change, but the analysis could not back up this conclusion adequately. Finally, Ibbs and Allen (1995) try to prove that "changes which occur late in a project are implemented less efficiently than changes that occur early." Their results, however, were not able to prove this hypothesis to a statistically significant level either although they did find a linear relationship between the amount of change and its timing.

Another CII study (Oberlender and Zeitoun 1993) provided a listing of impact factors when schedule was the driving force. The factors included: poor productivity due to personnel density, high cost to expedite materials, high cost for overtime, and lack of project planning. No quantitative analysis was completed.

2.6 Summary

Although some research has been attempted in the area of quantifying change order impacts on labor efficiency, the conclusions vary. A few attempts have been made at determining the impacts of timing of change, but no significant results have been quantified. Also, no serious study has researched the mechanical trades separately. For this reason, mechanical trades, with its unique intricacies because of its connected trade nature, is the focus of this thesis. The research will also attempt to provide significant quantitative results regarding change impacts and their timing on labor efficiency. A regression model will also be developed to predict the impacts on a selected job.

CHAPTER THREE: DATA COLLECTION AND CHARACTERISTICS

3.1 Introduction

The study of the impact of change orders is complicated and requires teamwork and cooperation between the research team and the construction industry. Therefore in order to provide meaningful results, much emphasis was placed on the data collection. Chapter 3 will present the methods and tools used in data collection and describe some of the characteristics of the data set.

3.2 Data Collection Tool Review

3.2.1 Formulating the Data Collection Tool

The data collection tool or questionnaire was developed using the following steps:

- The questionnaire used in the electrical contractor study was modified (Thomack 1996).
- Further modification was done using the data from the initial project investigation.
- Four contractors reviewed it and provided suggestions for improvement.
- Final improvements were made and it was sent to participating contractors.

A sample copy of the questionnaire is provided in Appendix A.

3.2.2 Section I: Company Data (Background)

The data collection tool began with background information on the company providing project information. The first area was for company address information. The rest of the section asked questions primarily dealing with size of the company measured in number of employees, number of projects completed, and the value of work completed in 1995. One final question asked the type of labor force used by the company. All surveyed contractors use unionized labor. This information provided an overall view of the size of each company, the type of work they specialize in, and the range between the smallest and largest companies.

3.2.3 Section II: Project Data

In order to understand each project better, this section asked a variety of questions. The first questions asked the project name, location, and the year of completion. Second, cost data are given for contract award amount, final project cost, total change order cost, and total mechanical cost broken down by specific type of work performed (i.e. HVAC, plumbing, process piping, or fire protection). Next, the respondent was asked to characterize the job as either impacted by change, impacted for other reasons, or unimpacted. A number of contract questions were followed by information relating to the project manager. The section ended with questions regarding project labor hours and cost as estimated initially and actually completed. The estimated and actual project duration for the mechanical trades were asked for as well as a labor distribution curve. Only a few companies provided information on their labor distribution.

3.2.4 Section III: Change Order Data

The change order section had both quantitative and qualitative questions. It began by asking the contractor to list change order data as in number, estimated cost and labor hours, and actual cost and labor hours. Next, the time of change was broken down as the contractor was asked to indicate in which schedule period of the job the changes occurred. The remaining questions were more qualitative and focused on areas of impact caused by both change orders and other factors. We asked whether or not the project was impacted by change to ensure that the project was in fact an impacted project. All responses were consistent.

3.3 Company Characteristics

A total of fourteen SMACNA and MCAA members participated in the study. They range in size from 41 full-time employees to 570, 19 projects completed in 1995 to 3,570, and from $5 million of mechanical construction put in place to over $76 million. The companies are headquartered in nine different states from all major areas of the United States except the Southwest.

3.4 Project Characteristics

The 43 mechanical construction projects were divided into six types. They are (1) commercial, (2) residential, (3) institutional, (4) industrial, (5) wastewater treatment plant, and (6) other as shown in Figure 3.1.

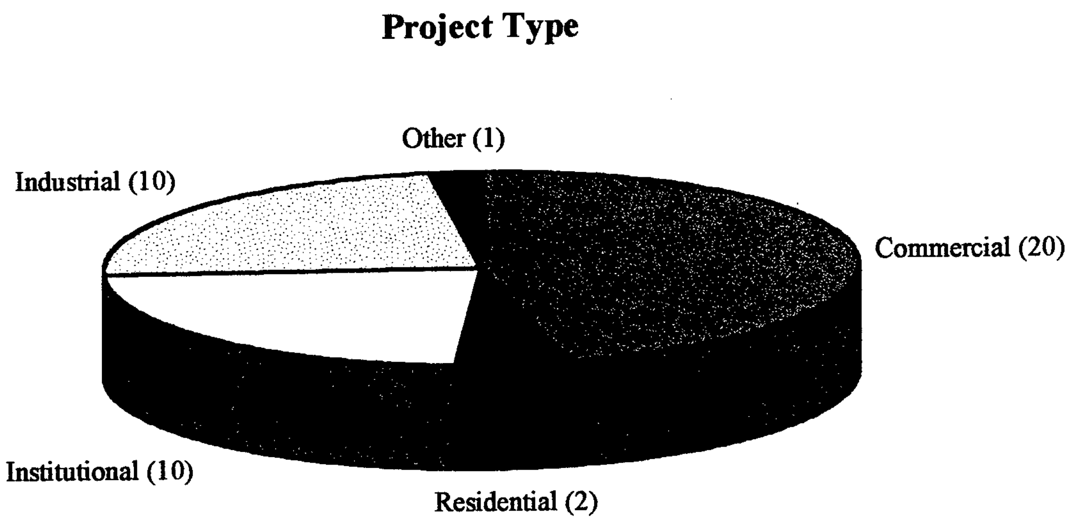

Figure 3.1 - Project Type

Figure 3.1 shows that 47% of the projects were commercial, 23% institutional, 23% industrial and 5% residential. The single "other" project was construction of a race track.

The projects were also characterized by specific types of mechanical construction performed. Some projects include two or more specific types. As shown in Figure 3.2, specific type categories included HVAC (Heating, Ventilation, and Air Conditioning) 44%, fire protection 5%, plumbing 32%, process piping 7%, and other 12%. "Other" projects included metal framing and partial electrical.

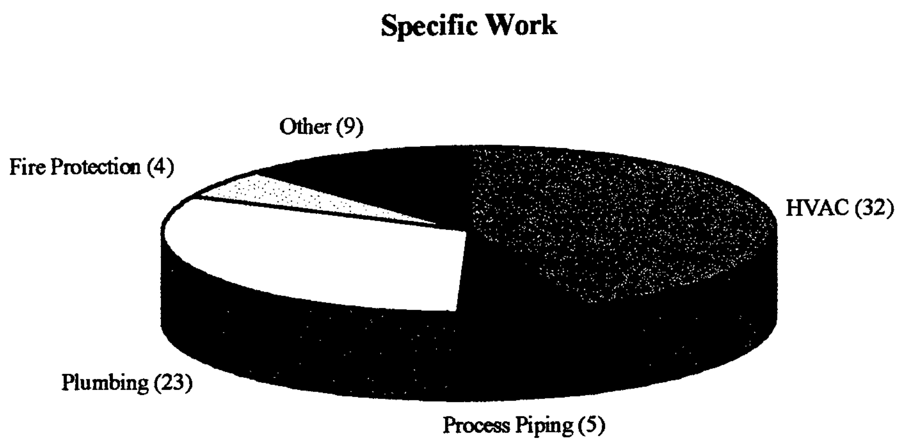

Figure 3.2 - Project Specific Work

The project delivery methods used were primarily design-bid-build with a few being completed as design-build. Figure 3.3 shows the breakdown using five categories by dividing the projects into whether or not a construction manager (CM) was used and including two projects that were accomplished using other methods.

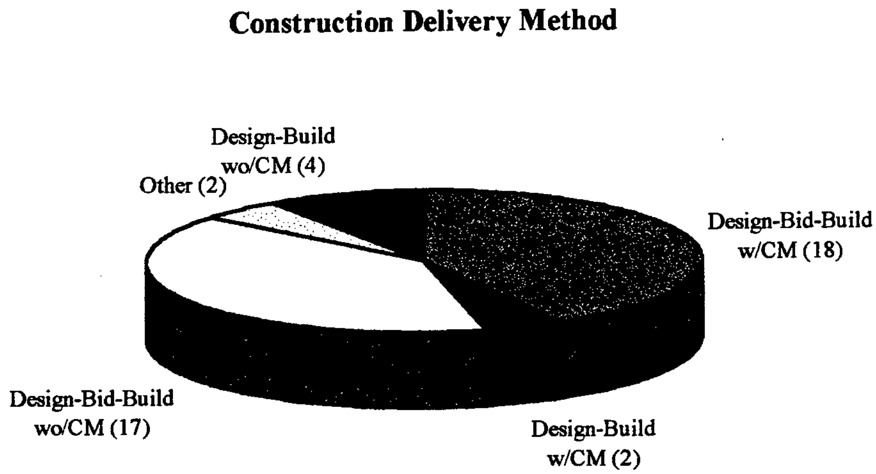

Figure 3.3 - Construction Delivery Methods

The contractors surveyed had three possible contractual relationships (1) as prime contractor, (2) separate prime contractor with another prime as the lead, or (3) as subcontractors. As shown in Figure 3.4, over 75% of all work was completed as subcontractors.

Contractual Role

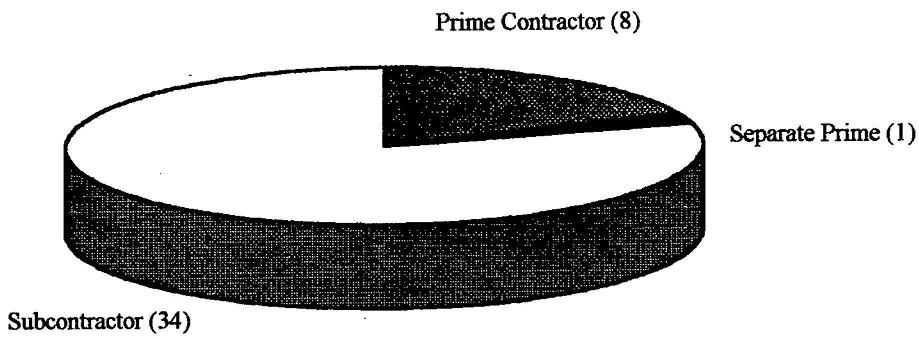

Figure 3.4 - Contractual Role

The contract types were either reimbursable cost or lump sum. As Figure 3.5 shows, most were lump sum.

Contract type

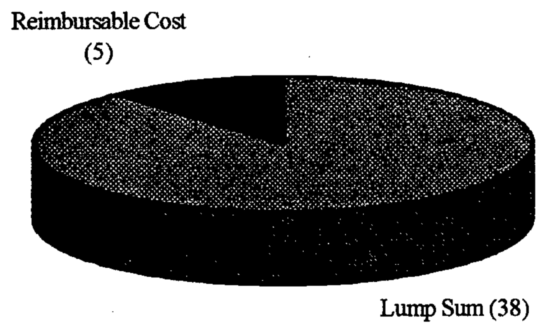

Figure 3.5 - Contract Type

The types of owners involved on the projects were approximately equally divided between private and public. Twenty-six of the projects involved private owners and the remaining 17 were public.

The projects ranged in size from just over 1,000 actual labor hours and $93,000 in mechanical construction cost to 163,000 actual labor hours and $11,686,000 in mechanical construction cost. Actual labor hours measures only the direct field labor. The average project has 26,475 actual labor hours while the median project has only 11,505 actual labor hours. Figure 3.6 shows the project size distribution.

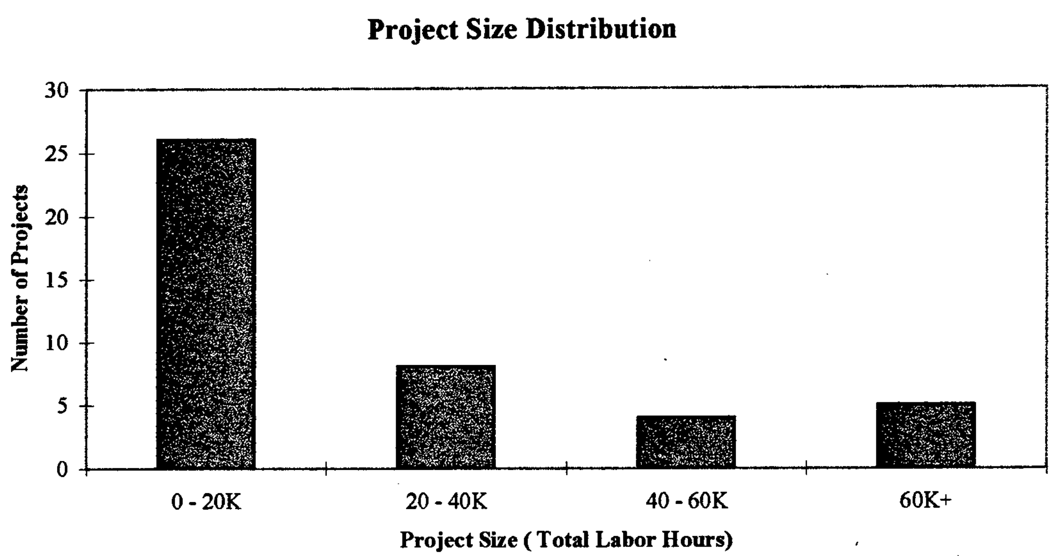

Figure 3.6 - Project Size Distribution

The projects had a large range in percent change as compared to total estimated hours. The actual range was from 0.7% to over 405%. Figure 3.7 shows the distribution.

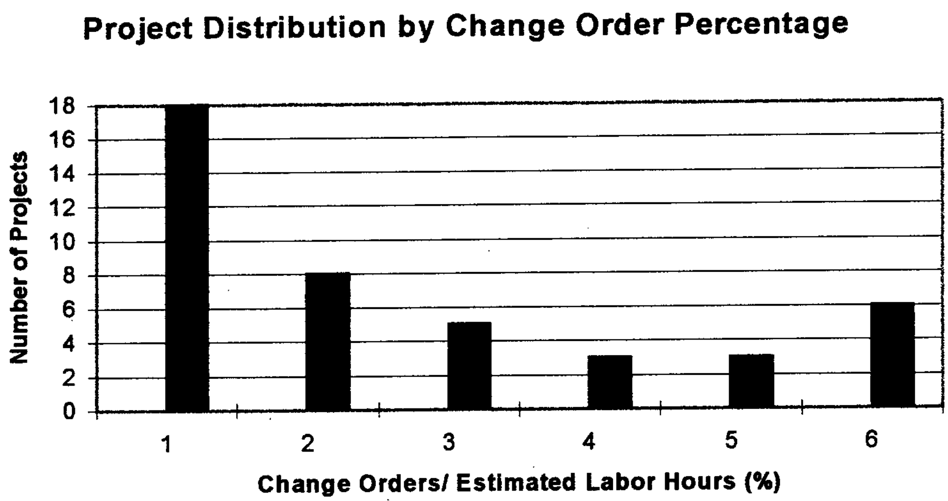

Figure 3.7 - Project Size Distribution by Percent Change

3.5 Impact Types

The forty-three projects were divided into three groups based on the project manager's evaluation of whether a particular project was significantly impacted by change orders, significantly impacted by other factors, or not impacted. Figure 3.8 provides the distribution.

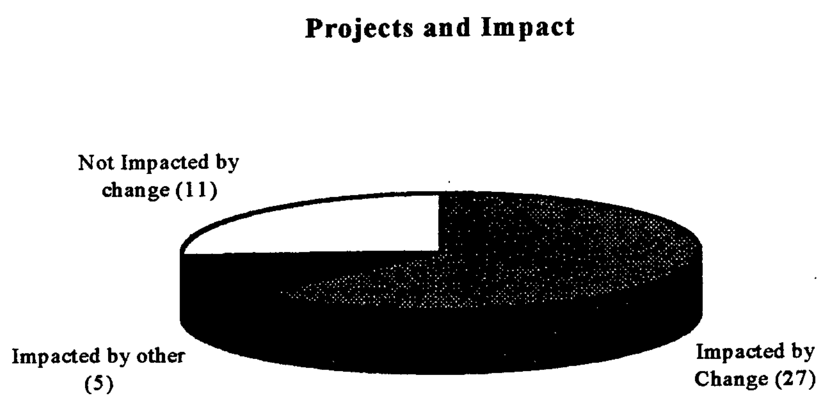

Figure 3.8 - Project Change Order Impact

The "impacted by other" projects were impacted by factors including: weather, material delivery, labor problems, poor management by prime contractor, poor scheduling, equipment malfunction and inefficiencies, and others. Projects were listed as not impacted by change when the change order work was either very small in comparison to the base job or when the changes had no significant effect on labor efficiency. One contractor noted that the change orders actually helped increase his efficiency by resource leveling his work crew.

In the analysis in Chapter 4, the projects will be grouped into only two categories: (1) projects impacted by change and (2) projects not impacted by change. Therefore, in some analyses the five impacted by other projects were not used in the analysis because they do not fit into the model in question.

3.6 Summary

Chapter 3 discussed the 43 projects compiled from 14 mechanical contractors. The data covers a wide range of projects that will be used to explore mathematical relationships in the next chapter. Project characteristics discussed were construction type, specific work, construction delivery method, contract payment type, contractual role, project size distribution, and change order impact.

CHAPTER FOUR: DATA ANALYSIS

4.1 Introduction

This chapter presents the major contribution of this thesis. The analysis is divided into two parts: (1) hypothesis testing and (2) regression analysis. The hypothesis testing portion will present hypotheses dealing with projects impacted or not impacted by change and evaluate these against the expected results in the areas of project management, percent change orders, labor efficiency, timing of change, and project size. Next, a regression analysis is performed to establish a model that predicts the impact on labor efficiency on future projects.

4.2 Hypothesis Testing

Hypothesis testing begins with the grouping of the data. Our data sample is divided into two discrete categories:

(1) Projects impacted by change, and

(2) Projects not impacted by change.

A t-test was used to analyze the differences in the data set. The t-test compares the data groups to determine if the differences between selected variables are statistically significant. Each test has a null hypothesis (H_o) which asserts that the two parameters, for example the mean of each data group, are equal for the variable in question (H_o: $\mu 1=\mu 2$) and an alternate hypothesis (H_a) which asserts that the two variables are different (H_a: $\mu 1 \neq \mu 2$). The analysis provides a level of significance, alpha, which should be specified by the database analyst, and a p-value. The level of significance, chosen to be 0.05 in this report, is the probability of

concluding the null hypothesis invalid when if fact it is valid. In other words, the level of significance is the probability of assuming the mean values of the two different populations are different when in fact they are equal. P-value can be thought of as the probability that the data at-hand supports the null hypothesis. If the p-value equals or is greater than specified alpha, H_0 is concluded. If the p-value is less than alpha, H_a is concluded and the parameter of interest is significantly different between the two groups.

Since the t-test assumes that the data are normally distributed, a non-parametric test such as a Wilcoxin Test was also performed. This test makes no assumptions, does a similar comparison of the data and gives a p-value that indicates the statistical significance of the difference between the data groups. A further description of the statistical analysis can be found in Appendix B.

In each of the following analyses, the variable in question will be given first, followed by a table and explanation of the results.

4.2.1 Change Order Impact and Project Management

Variable 1: Project Management - Does more experienced project management result in less impact by change?

This question is based on the premise that experienced project managers can reduce the impact of change because with their experience they can minimize the negative effects of change Table 4.1 shows the results for this analysis.

Table 4.1 - Hypothesis Testing Results for Factors Related to Project Management

Variable Name	Number of Projects		Mean Value		p-Value	
	Impacted	Unimpacted	Impacted	Unimpacted	T-Test	Wilcoxin
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Years in the Construction Industry (#)	27	11	18.87	21.18	0.513	0.573
Years with this Company (#)	27	11	12.17	18.18	0.093	0.073
Similar Type of Projects Performed (#)	27	11	20.48	44.18	0.152	0.279
Similar Size Projects Performed (#)	27	11	17.37	23.27	0.066	0.175

Clearly in all four cases, the average experience level is higher for the non-impacted jobs versus the impacted ones. However, the p-values never drop below the significance level of 0.05 so that no clear conclusion can be reached. In fact, the first variable, years in the

construction industry, is expected to be significant. However, the data does not support this hypothesis.

4.2.2 Change Order Impact and Amount of Change

Variable 2: Change Order Percent: Are projects with higher percentage of change more likely impacted by change?

Table 4.2 summarizes the results of the analysis completed between whether a project was impacted by change or not and change order labor hours divided by original estimated total hours taken as a percentage. The second analysis was completed using actual total hours versus estimated total hours.

Table 4.2 - Change Order Impact and the Amount of Change

Variable Name	Number of Projects		Mean Value %		P - Value	
					T-Test	Wilcoxin Test
(1)	Impacted (2)	Unimpacted (3)	Impacted (4)	Unimpacted (5)	(6)	(7)
Change Order Labor Hours/ Estimated Total Hours	27	16	50.27	6.22	0.0382	0.0001
Change Order Labor Hours/ Actual Total Hours	27	16	23.24	5.74	0.0023	0.0002

As one would expect, the results clearly indicate that the amount of change occurring on impacted jobs is much higher than on non-impacted jobs. In fact, based on total actual labor

hours, the average is 23.24% change for impacted jobs and only 5.74% for unimpacted jobs. The p-values indicate that this hypothesis is statistically significant.

4.2.3 Change Order Impact and Labor Efficiency

Variable 3: Labor Efficiency - Do projects impacted by change have lower labor efficiency?

This analysis uses the delta as defined in Chapter 1 and changes it to a percentage based on total estimated labor hours and total actual labor hours. These values are compared with whether or not the project was impacted by change. Table 4.3 shows the breakdown of projects.

Table 4.3 - Change Order Impact and Delta

Type of Change (1)	Positive Delta (2)	Negative Delta (3)	Total (4)
Impacted	20	7	27
Unimpacted	2	9	11

Table 4.3 indicates that the majority of impacted jobs have a positive delta and the majority of unimpacted jobs have a negative delta. These results show that the labor efficiency on a job that is not impacted by change is actually better than the original plan. When the delta is negative, this indicates that the contractor spent less overall labor hours on the base job than previously was planned. However, the results also show that contractors spend more time on

original "base" work when change orders impact the job. This is indicated by the majority of impacted jobs having positive deltas.

Table 4.4 further clarifies the differences between impacted and unimpacted jobs based on labor efficiency.

Table 4.4 - Change Order Impact and Delta % of Labor Hours

Variable Name	Number of Projects		Mean Value (%)		P - Value	
					T-Test	Wilcoxin Test
	Impacted	Unimpacted	Impacted	Unimpacted		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Delta Hours / Estimated Total Hours	27	11	17.53	-7.38	0.0092	0.0018
Delta Hours / Actual Total Hours	27	11	9.81	-8.07	0.0011	0.006

Table 4.4 confirms these same results with p-values indicating a high probability that the groups are different. The delta as a percentage of actual total labor hours is a positive 9.81 on average for impacted jobs and a negative (-) 8.07 for non-impacted jobs.

It should be noted that seven impacted and two non-impacted jobs do not fit the general result. After taking another detailed look at the data, it was found that the impacted jobs with negative delta values generally had small negative values and experienced project managers. On the other hand, the unimpacted projects with positive delta values were impacted by other factors as well. One was impacted by weather. The other project used a great proportion of

apprentice labor so that the company did well with labor cost but not with labor hours expended.

4.2.4 Impact and Change Order Timing

Variable 4: Change Order Timing - Are projects with major change toward the end of the schedule more impacted by that change than projects with the change occurring in the beginning?

This question is based on the premise that the later in the job a change order occurs the larger the impact on the labor force. This premise rises from the facts that it is harder to replan a project later in the schedule, more rework generally must be done including duplicate purchases for materials when the original material is installed but cannot be reused, and a loss of the learning curve and thus crew efficiency will occur.

An analysis was conducted using delta as a percent of total actual hours and comparing it with timing of change on a project. The timing variable is called weighted timing (WTIMING). WTIMING addresses the issue of timing and the amount of total change on a project.

Table 4.5 - Weighted Timing Example

Indicator Value	1	2	3	4	5	6	WTIMING	TIME
Period of Schedule	<0%	0 - 20 %	20 - 40 %	40 - 60 %	60 - 80 %	80 - 100 %		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Project #				Fraction of Change				
156	0.00	1.00	0.00	0.00	0.00	0.00	**2.00**	2
213	0.00	0.00	0.00	0.00	0.00	1.00	**6.00**	6
165	0.05	0.10	0.10	0.40	0.25	0.10	**4.45**	4
189	0.00	0.00	0.00	0.00	0.80	0.20	**5.20**	5
200	0.00	0.25	0.00	0.25	0.30	0.20	**4.20**	5

Contractors were asked to fill in the fraction of change for each period of the schedule. The sum of the fractions always is equal to unity (1.0). In order to calculate WTIMING, the fraction of change occurring in each portion of the schedule is multiplied by the indicator value. Indicator values are assigned to each period of the schedule beginning with one (1) for the period before construction starts and ending with six (6) for the period between 80 - 100%. The sum of these values for a given project is WTIMING.. For example, take project 156; all of the change occurred in the second column (0 - 20% of the project schedule) and so the solution for WTIMING is found by :

$$\mathbf{(1\times0) + (2\times1.00) + (3\times0) + (4\times0) + (5\times0) + (6\times0) = 2.00.}$$

Similarly, project 213 has a WTIMING of 6.00 since all of the change occurred between 80 and 100% of the project schedule. Project 165 is calculated as:

$$\mathbf{(1\times0.05) + (2\times0.10) + (3\times0.10) + (4\times0.40) + (5\times0.25) + (6\times0.10) = 4.45.}$$

The weighted variable WTIMING was used in the analysis because it is a more accurate predictor of when the greatest portion of the change occurred. At first, the indicator variable TIME was used. This variable indicated where the highest fraction of change occurred, but

did not take into consideration the size of the fraction or where the rest of the change occurred. For example, from Table 4.5, both projects 189 and 200 have the largest fraction of change occurring between 60 - 80% of project completion. This gives indicator values of TIME of five (5) for each project. However, the WTIMING values are 5.20 and 4.20, respectively, indicating that project 189 actually had significantly greater change toward the end than project 200.

After WTIMING was calculated for all projects, it was plotted against DELTA%TOT which equals Delta divided by Total Actual Hours and taken as a percentage.

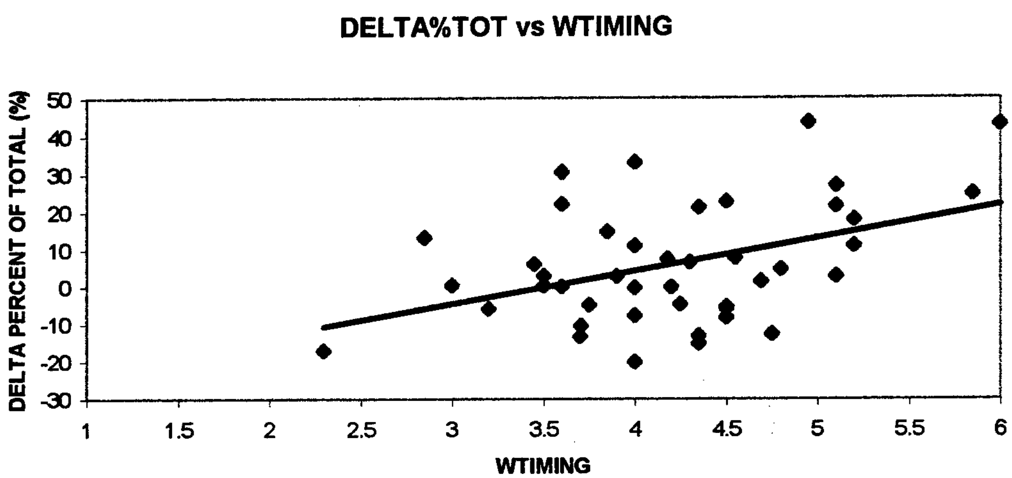

Figure 4.1 - Timing and Labor Efficiency

The plot indicates that as the value of weighted timing increases, delta as a percentage of total actual hours increases. Without considering other factors, the relationship between delta as a percent of total and WTIMING is shown in Equation (4.1).

$$\textbf{DELTA\%TOT} = \textbf{-27.7} + \textbf{8} \times \textbf{WTIMING} \qquad \textbf{(4.1)}$$

This equation quantifies the idea that change occurring toward the end of the schedule has more impact on the project.

4.2.5 Impact versus Project Size

Variable 5: Project Size - Are projects with greater size less impacted by change?

This analysis is based on the idea that larger projects are able to absorb change orders without being severely impacted. Larger projects tend to have a larger project management staff and more resources to offset some of the impact of change.

First, a simple t-test was performed to find the statistical significance in the relationship between impact and size using Estimated Hours. The p-value was 0.8053 and the mean values were 18,718 hours for impacted projects and 21,021 hours for unimpacted projects.

Second, a plot was made between Estimated Hours and DELTA%TOT.

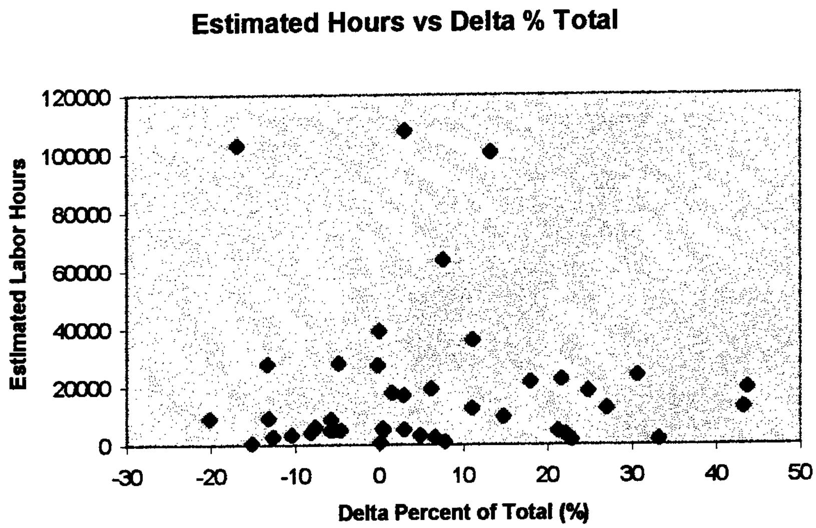

Figure 4.2 - Impact and Project Size in Estimated Hours

Next, the same was done using Total Actual Hours. The p-value for the t-test was 0.6720 when comparing Total Actual Hours vs. impact and the mean values were 28,317 for impacted and 23,367 for non-impacted. The plot of Actual Hours vs. Delta % Total Hours is shown in Figure 4.3.

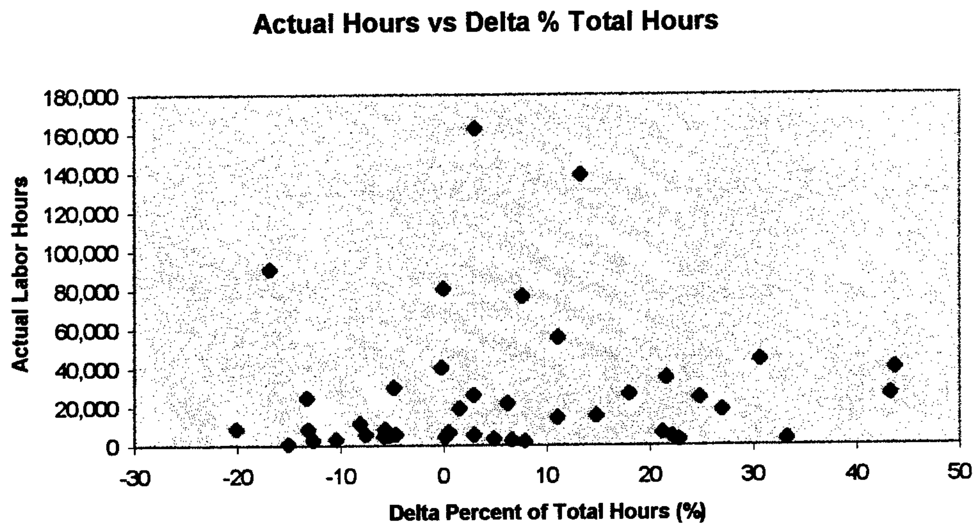

Figure 4.3 - Impact and Size in Actual Hours

Both analyses indicate that there is no conclusive difference between impacted and unimpacted projects and the size of the project. The plots show no trend in the project data and the p-values are large and indicate that there is no significant difference between impacted and unimpacted projects when comparing against size.

These results, found through hypothesis testing, were then used to assist in developing the regression model.

4.3 Regression Analysis

"Regression analysis may be broadly defined as the analysis of relationships among variables. It is one of the most useful statistical tools because it provides a simple method for establishing a functional relationship among variables" (Chaterjee and Price 1991). Regression analysis is used in this research to formulate a mathematical model to predict labor efficiency. Specifically, the stepwise method was used to establish a relationship between multiple independent variables and the dependent variable which is labor efficiency. A further explanation of regression analysis can be found in Appendix B.

4.3.1 Stepwise Regression

The methodology used was stepwise regression with experienced based judgement added to the analysis in choosing the independent variables to include in the model. Stepwise regression is essentially conducted by adding one independent variable to the model at a time, but also allowing an independent variable to be removed at any time. The particular order that variables are added to the model does not reflect the importance of any particular variable. The procedure determines the relationship between the dependent variable and various independent variables. When the model includes all significant independent variables, meaning (1) all variables left in the model are significant at the 0.05 level of significance and (2) all pertinent variables are included in the judgement of the analyst, it is selected as the final model. Next, the diagnostic checks are completed. These checks include (1) a plot of the

residuals to ensure that the data has no bias and (2) a plot of the actual and predicted values to verify the mathematical relationship. Then, the model is interpreted and an example using actual project data is illustrated. Finally, the model is validated using new project data to show its accuracy.

4.3.2 Data Characteristics

The data, as described in Chapter 3, represents 43 projects as part of the data set and another five projects used for model verification. The projects are from 14 mechanical contractors located in nine different states. The data and analysis range included projects with from 1,050 to 163,000 labor hours and from 0.7% to 80.1% change hours as compared to total actual hours. This is a very large range for mechanical construction and may explain a few of the outlying data points in the analysis. However, since the analysis covers such a large range of data, it is applicable for the majority of mechanical construction projects.

For the regression analysis, labor efficiency was found to be the dependent variable. Labor efficiency for the model is expressed as DELTA%TOT which is delta divided by total actual labor hours taken as a percentage. Some of the independent variables used in the regression are:

(1) Amount of change as a percentage of total actual hours (ESTCHNG%TOT)

(2) Impact of change (IMP)

(3) Time of change (WTIMING)

(4) Experience of project management staff (EXP)

Other possible independent variables exist in the data, for example type of work and labor cost. However, they are not included in this thesis simply because they were not statistically significant in the prediction of labor efficiency.

4.3.3 Regression Model Selection

The regression model contains all 43 projects worth of data. The dependent variable chosen is Delta as a percent of total actual hours (DELTA%TOT). Stepwise regression was used to develop a model to predict DELTA%TOT as shown in Table 4.6. Statistical Analysis System (SAS) was the computer software used.

Table 4.6 - Stepwise Regression Method

Step (1)	Independent Variable Entered (2)	Removed (3)	# Variables in Model (4)	Partial R-Squared (5)	Model R-Squared (6)	Level of Significance (Probability > F) (7)
1	WTIMING		1	0.1563	0.1563	0.0087
2	EXPERIENCE		2	0.0820	0.2382	0.0445
3	WTIMING(UNIMP)		3	0.0590	0.2972	0.0781
4	IMPACT(OTHER)		4	0.1378	0.4350	0.0042
5		EXPERIENCE	3	0.0096	0.4254	0.4277
6	ESTCHG%TOT		4	0.0903	0.5157	0.0113

No other independent variables were chosen to predict DELTA%TOT because they did not meet the 0.05 level of significance for entry into the model. EXPERIENCE was removed from the model because its level of significance of 0.4277, after adding the other independent variables, did not meet the 0.05 level of significance. The definitions of each independent variable used in the final regression model are:

(1) WTIMING - denotes the timing of the change for all projects as explained in section 4.2.4.

(2) EXPERIENCE - indicates the project manager's experience using number of years with the company.

(3) WTIMING(UNIMP) - denotes the adjustment factor that must be added to WTIMING for unimpacted projects.

(4) IMPACT(OTHER) - is the adjustment factor that must be added to the intercept for projects impacted by items other than change.

(5) ESTCHG%TOT - is the total estimated change order hours divided by total actual labor hours and taken as a percentage.

This final stepwise regression produced the results found in Tables 4.7 and 4.8. The sum of squares and mean square values are calculated for error.

Table 4.7 - Final Regression Model Values

Source (1)	Degrees of Freedom (2)	Sum of Squares (3)	Mean Square (4)	F Value (5)	Probability > F (6)
Model	4	5,437.17	1359.29	10.12	0.0001
Error	38	5,105.42	134.35		
Corrected Total	42	10,542.59			

Table 4.8 - Final Regression Variable Values

Variable (1)	Parameter Estimate (2)	Degrees of Freedom (3)	Sum of Squares (4)	Mean Square (5)	F Value (6)	Probability > F (7)
Intercept	-21.3454				4.42	0.0421
WTIMING	8.8049	1	1,963.91	1,963.91	14.62	0.0005
WTIMING(UNIMP)	-5.0260	1	3,045.39	3,045.39	22.67	0.0001
ESTCHG%TOT	-0.2812	1	952.33	952.33	7.09	0.0113
IMPACT(OTHER)	23.2569	1	1832.87	1832.87	13.64	0.0007

The selected models, based on the parameter estimates in Table 4.8, are:

For impacted projects,

$$\textbf{DELTA\%TOT} = \textbf{-21.3 - 0.3(ESTCHG\%TOT) + 8.8(WTIMING)} \qquad \textbf{(4.2)}$$

And for unimpacted projects,

$$\textbf{DELTA\%TOT} = \textbf{-21.3 - 0.3(ESTCHG\%TOT) + 3.8(WTIMING)} \qquad \textbf{(4.3)}$$

Notes:

(1) The predicted DELTA%TOT should never exceed the actual amount.

(2) The value for ESTCHG%TOT must be entered as a percentage, (i.e. 10% = 10).

The model has two similar equations with the difference being whether or not the project was impacted by change. The model has an R-squared value of 0.517 and an adjusted R-squared value of 0.4648. The R-squared value indicates that the variability is explained by the independent variables provided.

Diagnostic Checking

Diagnostic checking was used to determine if there was bias in the model. As stated earlier, these checks include (1) a plot of the residuals to ensure that the data has no bias and (2) a plot of the actual and predicted values to verify the mathematical relationship. A residual is the difference between a data point and its predicted value. Figure 4.4 shows the predicted value of delta versus the residuals.

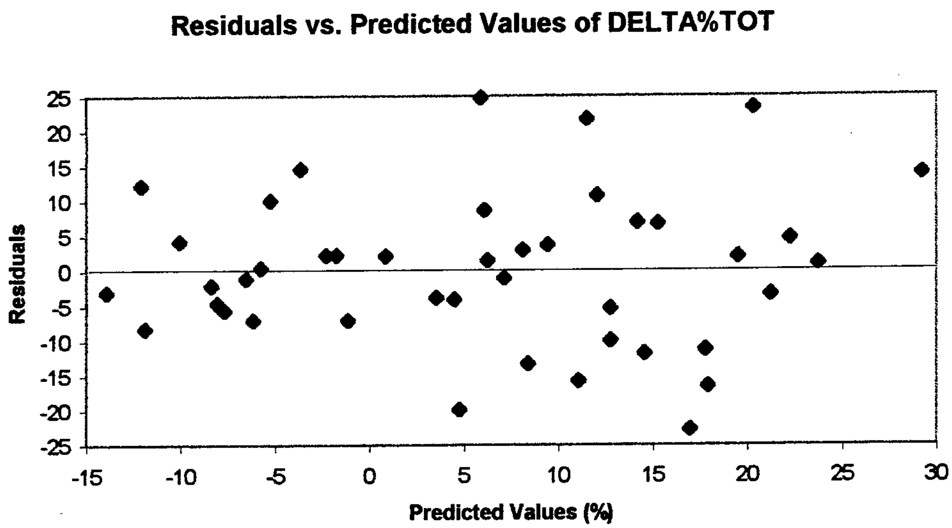

Figure 4.4 - Residuals vs. Predicted Values

This plot shows that the residual values are random. Thus, it appears that the model is not biased. Figure 4.5 shows the original delta values as given by contractors plotted versus the predicted delta value as given by the model. In this case, the data indicate a linear relationship as was expected.

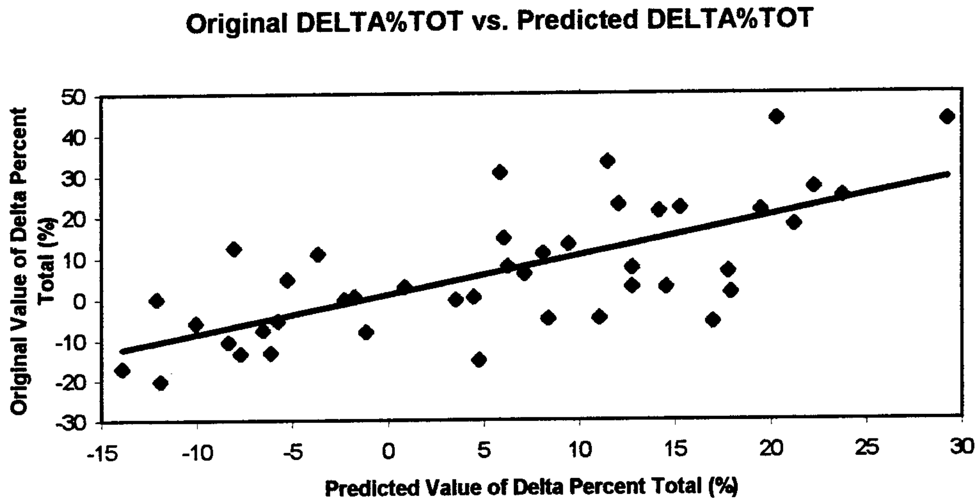

Figure 4.5 - Model Predicted Value vs. Original Value

4.3.4 Model Interpretation and Example

The regression models are shown again in equations (4.4) and (4.5).

For impacted projects the predictive model is,

$$\mathbf{DELTA\%TOT = -21.34 - 0.28(ESTCHG\%TOT) + 8.80(WTIMING)} \qquad \mathbf{(4.4)}$$

and for unimpacted projects the model is,

$$\mathbf{DELTA\%TOT = -21.34 - 0.28(ESTCHG\%TOT) + 3.78(WTIMING)} \qquad \mathbf{(4.5)}$$

The final regression model was developed using a number of variables as listed above. Therefore, it cannot be broken into pieces for interpretation. The model must be taken as a whole. The separate models for impacted and unimpacted projects indicate that the slope of the regression line, although always positive, is much higher for an impacted job than an

unimpacted one. The different slopes are indicated by the WTIMING values of 8.8 for impacted jobs and 3.8 for unimpacted jobs.

Example

To illustrate how the regression model works, here is an example using data from one of the original contractor's projects:

- type of impact = impacted by change;
- original contract estimate for direct labor hours = 19,413 hours;
- total actual labor hours expended on the job = 22,106 hours;
- total change order labor hours estimated for the job = 1,325 hours;
- fraction of change occurring before the start of the job = 0;
- fraction of change occurring between 0-20% of the project schedule = 0.15;
- fraction of change occurring between 20-40% of the project schedule = 0.45;
- fraction of change occurring between 40-60% of the project schedule = 0.25;
- fraction of change occurring between 60-80% of the project schedule = 0.10; and
- fraction of change occurring between 80-100% of the project schedule = 0.05.

The actual labor hours expended on the original project work, the base, is calculated as:

$$\text{Base} = 22{,}106 - 1{,}325 = 20{,}781 \text{ Hours}$$

The labor efficiency, delta, is calculated by subtracting the original estimate from the base:

$$\text{Delta} = 20{,}781 - 19{,}413 = \mathbf{1{,}368\ Hours}$$

Now, using the regression model equation 4.2 for a project impacted by change and the same data:

$$\text{DELTA\%TOT} = -21.345 - 0.2812(\text{ESTCHG\%TOT}) + 8.8048(\text{WRANK}) \quad (4.2)$$

From section 4.2.4:

$$\text{WRANK} = 1(0) + 2(0.15) + 3(0.45) + 4(0.25) + 5(0.10) + 6(0.05) = 3.45$$

and,

$$\text{ESTCHG\%TOT} = 1{,}325/(20{,}781) \times 100 = 6.38\%$$

therefore,

$$\text{DELTA\%TOT} = -21.345 - 0.2812(6.38) + 8.8048(3.45) = 7.42\ \%$$

$$\text{DELTA} = 7.42\%/100 \times 22{,}106 = \mathbf{1{,}542\ Hours}$$

In this case the predicted value of delta is 1,542 hours as compared to the actual value of 1,368 hours. In this case, the accepted value for delta is 1,368 hours since no value above the actual value is allowed.

Model Validation

Data from five additional projects were collected and used to validate the final regression models for both impacted and unimpacted jobs. The results are summarized in Table 4.9.

Table 4.9 - Regression Model Validation Results

Project # (1)	Impact (2)	Percent Change % (3)	Actual Delta (Hours) (4)	Predicted Delta (Hours) (5)	DELTA%TOT Difference (%) (6)
1	2	5.7	-148	-310	0.92
2	2	24.7	-139.5	-549	7.77
3	2	2.0	115	-80	16.38
4	2	1.8	-617.5	-236	-12.29
5	1	11.7	3449	1353	20.4

The validation for the model is inadequate, particularly for impacted projects. The four unimpacted projects fit reasonably into the model. The one impacted project had large amounts of change due to errors and omissions in the design and not from owner initiated changes like the data base projects. More project data will have to be collected for better validation.

4.4 Summary

Hypothesis testing identified a number of variables that differ between impacted and unimpacted projects. Table 4.10 summarizes the results of this statistical analysis.

Table 4.10 - Hypothesis Testing Results

Tested Variable (1)	Result (2)
Project Management Experience	Inconclusive
Amount of Change	Supports
Labor Efficiency (Delta)	Supports
Timing of Change	Supports
Size of Project	Inconclusive

The regression analysis on the forty-three sets of project data produced a model that predicts the amount of impact that change has on mechanical construction projects. The impact is measured in extra labor hours needed to complete the originally contracted work and is dependent upon whether or not the job was significantly impacted by change, the amount of change and the timing of the change. The model shows that there is significant impact on labor efficiency when change occurs, but it does not effectively address what factors cause the impact. These factors will be addressed in Chapter 5.

CHAPTER FIVE: TOOLS FOR MECHANICAL CONTRACTORS

5.1 Introduction

This study has shown that change orders affect labor efficiency on a "macro" scale. However, most contractors had difficulty answering all the questions on the survey and in some cases had to estimate values, particularly on timing of change. Therefore, it is necessary for contractors to track change orders and their impacts more carefully in order to manage each project more effectively and gather the information necessary to understand how the change orders affected each project. Two tools are described in the following sections to help contractors understand and track change orders and their impacts.

5.2 Change Order Tracking Tool

A change order tracking tool is necessary to provide the detailed information necessary to understand the full impact of change orders. However, if the tool is too complicated or too time consuming, the project supervisor will have little incentive to use it and the tool becomes useless. With this in mind, the objectives of this change order tracking tool are:

1. To record change order information needed to reasonably estimate the impact of change on labor efficiency and

2. To remain simple enough that a project supervisor can complete the daily form(s) in minimal time say ten minutes.

If these objectives can be met, contractors will have a valuable tool to record actual change impacts.

The proposed method for recording change information involves the project supervisor or foreman, since he/she is the person continuously on the project and close enough to the work. Not only must the recorder be aware of all change orders, he/she must be on site to view and record the daily change order work and its impacts. The recorder will need to fill out the proposed form every day that change impacts his crew's work. At the end of each month, the daily reports will be compiled into a monthly summary that will be reviewed by the project manager and project supervisor or foreman. At the end of the project, the monthly reports will be compiled into one final summary report. With this detailed information, contractors can then evaluate the impacts of change on each of their projects and reduce their risk in the future by knowing, to a reasonable extent, what are their costs. The Daily Change Order Log, Monthly Change Order Summary, and Project Change Order Summary are include as Appendix D. The Daily Change Order Log was adapted from Thomack (1996).

5.3 Checklist of Change Order Impacts

Contractors can also learn from a simpler tool when evaluating the risk of change order impact. This tool is simply a checklist of the possible impacts. The following list is a compilation of change order impacts on labor efficiency and their explanations as found through experienced professionals and the cited references. Appendix E contains a sample checklist.

Management Factors

Management factors that affect labor productivity include a ripple effect to other trades. For instance, a change order to an HVAC system will have ripple effects to the contractor placing the concrete decks of a building when the ductwork must pass through openings in the decks. The delay in the placement and forming of the required mechanical openings will disrupt the formwork, reinforcing steel, and concrete subcontractors. Crew supervision may become diluted as foremen and supervisors spend their time on increased project administration, more meetings, and more coordination with other project team members. There may also be delays caused by obsolete plans and specifications that now have errors and omissions and must be re-designed.

Material, Tool, and Equipment Factors

Change can cause large delays. New materials will have to be expedited, causing double handling of material. Equipment and tools must be available and labor crews will have to spend the time to obtain and maintain them. Crews may also waste time locating equipment as it is continually moved around the site. Due to changed workspace conditions, specialized equipment may now be needed such as unusual scaffolding to fit into cramped locations. Also, more lighting and workspace ventilation may be required.

Crew Factors

There are many factors that may directly affect the crew's performance. Overtime and shiftwork, required to meet new deadlines, may produce inefficiencies as material and

equipment support personnel may not be available. Crews may become fatigued, the required amount of labor may not be available, and proper crew mix may be not be possible. Crews may also become less efficient when they become unbalanced, have continuous fluctuation in their size and make-up, and have key personnel reassigned. Continually starting and stopping of work causes losses in learning curve, job rhythm, and momentum. Also, many change orders may require crews to work out of the normal, most efficient sequence.

Work Space Factors

Since change disrupts the scheduled sequence of work, impact factors related to work space are relevant. Schedule extensions may result in performing work in an unplanned season in which weather impacts the construction. Efficiency will drop as work space becomes crowded due to larger crews, trade stacking, joint occupancy, or even beneficial occupancy by the owner. In some cases, the construction may have proceeded to the point that portions of the project, already completed by other contractors, will have to be worked around and protected from damage. Crowded work conditions are also more hazardous to the workers and may require crews to work the job in pieces under harsh conditions.

5.4 Summary

As contractors become more knowledgeable about the impact of change and the decrease in labor efficiency, they will be better equipped to present their case to the owner. The change order impact logs and impact checklist, described above, will help them gain the information

required to present a solid case. The tools will also help all project team members understand the full impacts of change.

CHAPTER SIX: SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

6.1 Summary

Change orders are a common part of the construction process. In order for contractors and owners to agree on cost of a change, its full impact must be understood. This thesis focused on the impacts of change on labor efficiency in mechanical construction since labor cost is the largest risk to the contractor and the hardest to quantify. The average labor cost for the projects used in this research was 34.5% of the total cost. Chapter 1 introduced change and its effects and presented the methodology used for this research. The methodology used includes: (1) Conduct Literature Review, (2) Collect Initial Data, (3) Analyze Initial Data, (4) Formulate Data Collection Tool, (5) Contractor Evaluation of Data Collection Tool, (6) Contact Interested Contractors, (7) Distribute Data Collection Tool, (8) Collect Data, (9) Review and Clarify Data, (10) Analyze Data, (11) Develop Impact Model, and (12) Summarize Conclusions and Recommendations.

Chapter 2 presented a literature review. Change order topics covered were: change order management, change order pricing, change impacts on productivity, and timing of change orders and their impacts. The literature review uncovered the limited amount of information available quantifying the impacts of change on productivity, especially when change order timing is considered. Due to the lack of knowledge regarding change orders and their quantitative impacts on labor efficiency, this research was started.

Taking a look at the contractors, project data, and change data was the topic for Chapter 3. First, the Data Collection Tool was discussed. Then, the chapter broke down the data acquired from fourteen MCAA and SMACNA contractors covering 43 projects. The project break down discussion included: project type, specific work, construction delivery method, contractual role, contract type, project size distribution, and change order impact type.

Chapter 4 presented the data analysis which began with hypothesis testing covering change order impact and how it was related to: (1) project management experience, (2) change order amount, (3) labor efficiency, (4) change order timing, and (5) project size. Next, stepwise regression was used to develop a model to estimate change order impact on labor efficiency. Labor efficiency was defined by delta which was the difference between the base (or normal project hours) and the original project estimate. The regression analysis was an iterative process that determined a model with the best fit to the data. The final predictive models are:

For impacted projects,

$$\textbf{DELTA\%TOT} = \textbf{-21.3 - 0.3(ESTCHNG\%TOT) + 8.8(WTIMING)} \qquad \textbf{(6.1)}$$

And for unimpacted projects,

$$\textbf{DELTA\%TOT} = \textbf{-21.3 - 0.3(ESTCHNG\%TOT) + 3.8(WTIMING)} \qquad \textbf{(6.2)}$$

Two equations are used because of the differences between an impacted project (1) and an unimpacted one (2). Both equations show that when change occurs, WTIMING is the most import factor in deciding the ultimate impact on labor efficiency. This model was then verified using new project information.

Chapter 5 presented two tools to help contractors understand and manage change order impacts. The first tool is a system of change order logs used by project supervisors to document change impact on a daily basis and then summarize it monthly and at the end of the job. The second tool is a checklist provided so that managers are aware of the numerous change order impact possibilities on labor efficiency.

6.2 Recommendations

The research conducted for this thesis has produced significant results for contractors to implement immediately, while taking into consideration its limits. Three recommendations are given: (1) use of these conclusions, (2) implementation of change order record keeping, and (3) future research.

6.2.1 Future Use of Regression Model

The linear regression model developed can be used to predict the average impact of labor efficiency. However, the model has its limits as discussed earlier. The model is not designed to predicted labor efficiency for projects that have major impact factors other than change. Also, all projects must be between 1,050 and 163,000 labor hours and 0.7% and 80% change with respect to total actual labor hours. Much of the variation in the model is attributed to the nature of construction, in which all projects are unique. However, barring unusual circumstances on a mechanical construction project, the model will result in a reasonable estimate of the impact of change on labor efficiency.

6.2.2 Change Order Record Keeping

Contractors on average do a poor job in tracking the impact of changes. Therefore, it is recommended that change order record keeping be implemented today by using simple daily logs that should take only a few minutes. Contractors will then be able to document the impacts on their workforce. Since labor is the highest risk for contractors completing change orders, this documentation can be used to negotiate with owners with a higher base of knowledge.

6.2.3 Future Research

To improve our knowledge of change order impacts, more research is required in the future. The research should branch out to take in many other project attributes. Possible follow-on research should include: expansion of this study on change order impacts on labor efficiency at the macro level, a more detailed study of change order impacts at the micro level, and further research on change involving all trades in the construction industry.

This study, its conclusions, and regression model can all be improved. First, by collecting more project data, the statistical analysis will gain greater significance. Secondly, by collecting data from contractors using the daily change order logs, the analysis will be able to more accurately quantify change order impacts because precise data will be available and better methods than the Total Cost Method can be used. Precise data will help eliminate the assumptions used and eliminate the impact factors that are not related to change. This "normalized" data will be more accurate than the overall approach taken. Finally, more and

precise data will allow analyses to be done on subsets of the data. For instance, the analysis could break down the project data base into construction type or even specific work. Also, the analysis should take into account the actual number and size of each change as well as the owner's project budget and the effects that an inadequate budget had on change order impacts. Experienced construction officials have indicated that projects with tight budgets are negatively impacted by any change since the owner struggles to have the work completed at minimum to no cost.

Quantifying the impacts of project change should also be carried out at the micro or project specific level. This approach will allow actual productivity measurements to be taken. Change orders and their impacts will then be monitored closely on a daily basis. Another way to look at time of change should be studied. Instead of looking at the amount of change in each period of the schedule, the lead time for each change should be evaluated along with whether the change was owner initiated or evolved from errors and omissions in the plans and specifications. Also, this research evaluated impact based on the experience of the project manager assuming that a person with more time in the position would handle change more effectively. However, research needs to be done in evaluating the effectiveness of the project manager, maybe based on profitability, since this variable may be more appropriated than experience. Micro level research, however, will be tedious and time consuming, but will produce valuable results.

This research only looked at quantifying change order impacts in the mechanical construction field. Other studies have included electrical, civil, and architectural construction as well. More research should be done in all construction trades and pooled when applicable to find greater results. Although combining all types of construction projects will provide more general results, the conclusions may have a larger impact on owners than more specific studies.

6.3 Conclusions

The purpose of this thesis was to quantify the impacts of change orders on labor efficiency in the mechanical construction industry. This was accomplished through the collection and analysis of 43 projects from 14 contractors. The statistical analysis showed that significant differences existed between impacted and unimpacted projects. The amount of change was much larger and the decrease in labor efficiency more severe for impacted projects. Also, the analysis showed that the later in the job the change occurred, the larger the decrease in labor efficiency. Linear regression was used to develop a model to predict change impact on labor efficiency. When the model is used within set parameters, it produces a reasonable value for the loss in labor efficiency.

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APPENDIX A: DATA COLLECTION TOOL

Change Order Project Information Sheet

SECTION I: COMPANY DATA (BACKGROUND)

Company Name ____

Company Address ____

Telephone ____

Fax ____

(Alternative: Please attach business card)

1. What position do you hold within your company?
   - ☐ Owner/President
   - ☐ Vice President
   - ☐ Project Manager
   - ☐ Superintendent
   - ☐ Other (please specify)________________________

2. Please indicate the types of projects most commonly undertaken by your company. (Check as many as you feel appropriate)
   - ☐ Residential
   - ☐ Commercial
   - ☐ Waste Water Treatment
   - ☐ Institutional
   - ☐ Industrial
   - ☐ Other (please specify)________________________

3. Which of the following best describes your companies labor work force?
   - ☐ Union
   - ☐ Open Shop
   - ☐ Merit Shop

4. In 1995, what was the number of projects your company completed? ________________#

5. In 1995, what was the dollar value of ***contracts awarded*** to your company? ____________$

6. In 1995, what was the dollar value of ***work put in place*** by your company? ____________$

7. How many direct labor personnel (such as plumbers, fitters, sheet metal workers, etc.) are currently employed full-time by your company? ____________#

8. How many total full-time employees are currently employed by your company? ____________#

Change Order Project Information Sheet

SECTION II: PROJECT DATA (PLEASE NOTE: MULTIPLE COPIES OF THIS SECTION ARE REQUIRED.)

Project Name ______________________________

Project Location ______________________________

Year Construction was Complete 19______ (year)

Contract Award Amount $______________________________

Final Total Project Cost $______________________________

Total Change Order Cost $______________________________

Total Mechanical Cost Your Company Provided:

HVAC $______________________________
Plumbing $______________________________
Fire Protection $______________________________
Other (please specify) $______________________________

Name of person completing this section of the survey______________________________
(Please attach business card)

For the following question, please use your experience within the industry to characterize this particular job as it relates to others of similar size and duration. Impacted means simply that this job was affected by change orders to a degree greater than was anticipated.

Job Characterization (circle one): Impacted by change   Impacted for other reasons (weather, material problems, strike, etc.)   Unimpacted

1. Project Type

A. General Category (check one)
- ☐ Residential (Single and/or multi-family housing)
- ☐ Commercial (Banks, retail, schools, office buildings, etc.)
- ☐ Institutional (Hospitals and correctional facilities)
- ☐ Industrial (Manufacturing or process plants, paper mills, etc.)
- ☐ Wastewater Treatment Plant
- ☐ Other (Please specify) ______________________________

B. Specific Work Provided by Your Company (check as many as apply)
- ☐ HVAC
- ☐ Plumbing
- ☐ Fire Protection
- ☐ Other (Please specify) ______________________________

2. The project delivery approach for this project was:
   - ☐ Design-bid-build
   - ☐ Design-build or engineer/procure/construct (EPC)
     Was a joint venture formed between the design firm and the constructor?
     ☐ Yes ☐ No
   - ☐ Other (Please specify) ______________________

   Was a construction manager used on this project? ☐ Yes ☐ No

3. On this contract your company was:
   - ☐ Prime Contractor
   - ☐ Separate prime with lead contractor
   - ☐ Subcontractor To ☐ GC ☐ CM ☐ Other ______________ (Please specify)

4. The contract type on this project was:
   - ☐ Lump sum
   - ☐ Reimbursable cost ☐ % fee ☐ fixed fee
     Was a guaranteed maximum price used on this project? ☐ Yes ☐ No
   - ☐ Unit price
   - ☐ Other (Please specify) ______________________

5. The Owner was:
   - ☐ Private sector owner
   - ☐ Public (Government)

6. Please estimate the number of full time equivalent person(s) (2 half time = 1 full time) in your project management staff (e.g., project manager, superintendent(s), project engineer(s), and field engineer(s), *excludes* foremen, clerical support staff and general work force.
   ____________ #

7. Please answer the following questions as they pertain to the project manager on the job:

   Total years worked in the construction industry (all positions) ________years

   Total years worked for this company (all positions) ________years

   Number of projects worked on of this construction type ________#

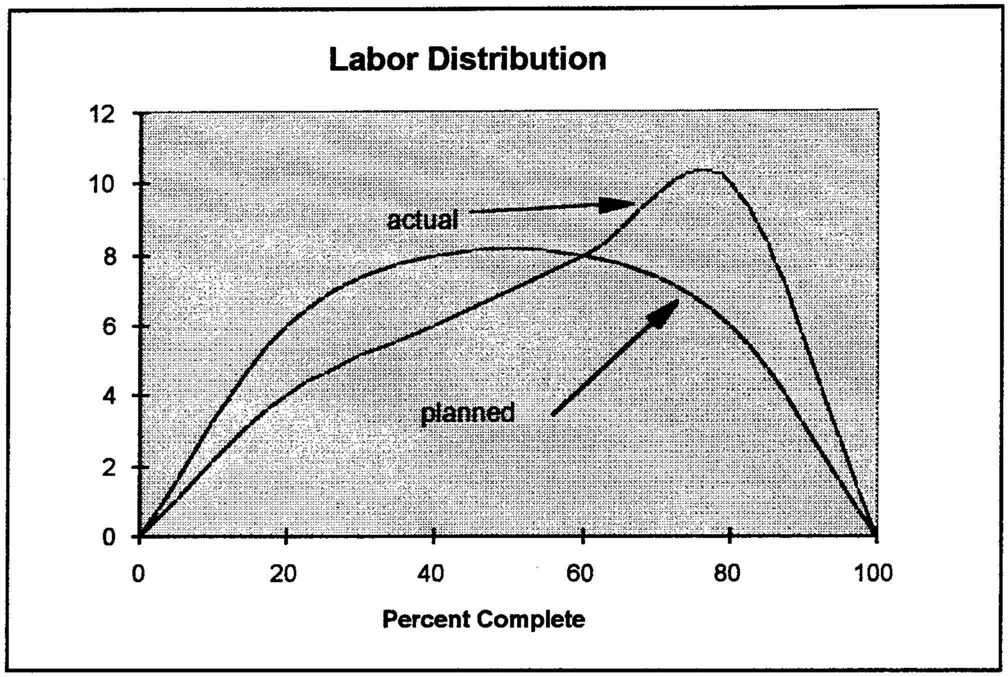
   Number of projects worked on of this approximate size (cost & duration) ________#

Please answer the following questions as they pertain to the mechanical portion of the project.

8. The base estimated total labor hours for the job was ______________Hours
9. The estimated total labor cost for the job was $______________
10. The completed amount of labor hours subcontracted was ______________Hours
11. The completed amount of labor cost subcontracted was $______________

12. The completed actual total labor hours for the job was ____________________ Hours
13. The completed actual total labor cost for the job was $____________________
14. The estimated mechanical construction duration ____________________ Months
15. The actual mechanical construction duration ____________________ Months

16. If available, please attach a planned and actual labor distribution similar to the one shown below. You may also choose to draw it at the bottom of this page.



Change Order Project Information Sheet

SECTION III: CHANGE ORDER DATA (PLEASE NOTE: MULTIPLE COPIES OF THIS SECTION ARE REQUIRED)

The purpose of our study is to determine the impact of change orders on labor productivity. The following questions pertain to change orders on the selected project. For background information, we are considering change orders to be any owner-acknowledged change that is implemented *after* the start of construction.

1. Please indicate the number of change orders that occurred on this job. ____________________#
2. The estimated labor hours for all change orders is ____________________Hours
3. The estimated labor cost for all change orders is $____________________
4. The actual labor hours for all change orders is ____________________Hours
5. The actual labor cost for all change orders is $____________________
6. Please *approximate* the timing of the changes:

Project % Complete (measure in labor hours expended)	**% of Change Orders That Had Occurred**
Before start	________________%
0 - 20%	________________%
21 - 40%	________________%
41 - 60%	________________%
61 - 80%	________________%
81 - 100%	________________%
	(Total = 100%)

7. Please list the impacts that change orders have caused on this project (i.e., rework, increased overhead, increased project planning and meetings, material problems, equipment changes, etc.).

Exploring the Delta

Figure 1 below illustrates the hypothesis being investigated in this research project.

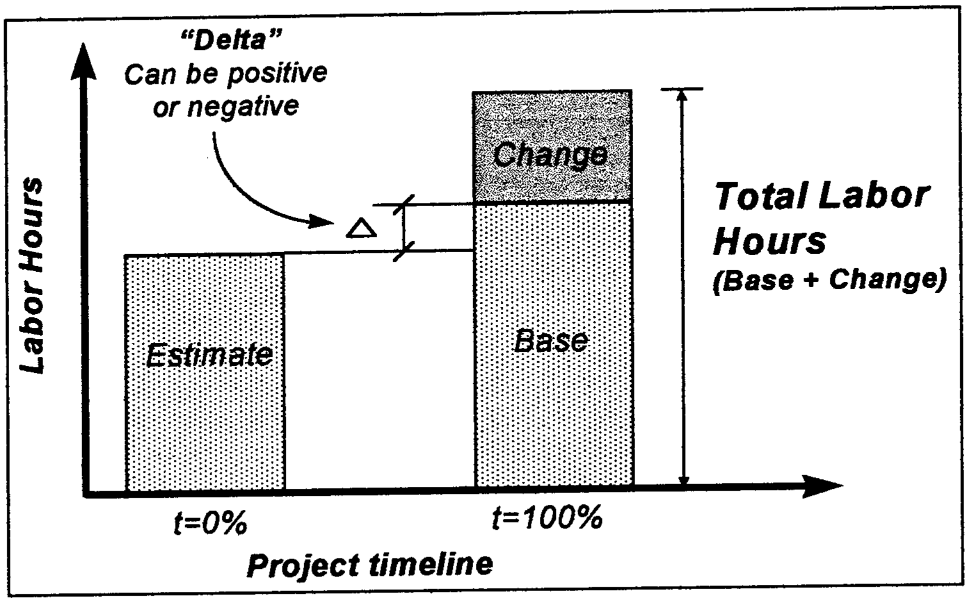


FIGURE 1. - The Delta

Many events impact a project during construction. In our efforts to better understand and explain the "delta" or difference between the base and estimated labor hours, we need to know the following information regarding the project.

1. Please rate the following as to the impact on productivity for this job, where 1 is minimal impact and 5 is significant impact:

Change Orders	**No Impact 1 2 3 4 5**
Weather Conditions	**No Impact 1 2 3 4 5**
Overtime	**No Impact 1 2 3 4 5**
Shift work	**No Impact 1 2 3 4 5**
Schedule Compression (Planned or Unplanned)	**No Impact 1 2 3 4 5**
Labor Problems (Disputed, poor management, etc.)	**No Impact 1 2 3 4 5**
Trade Stacking (Working in confined areas with other trades)	**No Impact 1 2 3 4 5**
Material Problems (Supplier problems, unavailability)	**No Impact 1 2 3 4 5**
Sequencing of Work (Forced to work out of sequence)	**No Impact 1 2 3 4 5**
Absenteeism and Turnover (Disruption of crew chemistry)	**No Impact 1 2 3 4 5**

Were there any other conditions which may have impacted labor productivity? Please explain:

i)

ii)

iii)

iv)

The research team is looking at change order impacts on schedule related items. For the questions 2-4 use the following definitions for clarification.

Magnitude means the average size and/or length of the change orders. What we are looking for is an answer that conveys whether the total change order hours came from a small number of large changes or a large number of small changes.

Frequency means the time over which the changes occurred. What we are exploring here is whether the changes were evenly spread out over the life of the project or did they come in intervals, i.e., mostly at the beginning, middle, or end of the project.

2. The total **number** of change orders experienced on this job as compared to a typical job of this size and type was:
   ☐ Above average ☐ Average ☐ Below average

3. The **magnitude** of change orders experienced on this job as compared to others was:
   ☐ Above average ☐ Average ☐ Below average

4. The **frequency** of change orders experienced on this job as compared to others was:
   ☐ Above average ☐ Average ☐ Below average

APPENDIX B: STATISTICS DISCUSSION

Statistics Discussion

Hypothesis Testing

For further information see Chaterjee and Price (1991) or Thomas and Napolitan (1995). Three statistical tests were used in the hypothesis testing phase of the analysis. The three tests used were the t-test, anova test and the Wilcoxin test. A t-test was used to analyze the differences in two sets of data while an anova test was used for analyzing three or more sets of data. Both assume a normal distribution to the data. The Wilcoxin test, on the other hand, does not assume a normal distribution. Therefore, when the results are compared between the t-test or anova test and the Wilcoxin test, no significant difference in the results should be found if the data are normally distributed

The tests compare data groups to determine if the differences between selected variables are statistically significant. Each test has a null hypothesis (H_o) which claims that the two parameters are equal for the variable in question (H_o: $\mu 1=\mu 2$) and an alternate hypothesis (H_a) which claims that the two variables are different (H_a: $\mu 1 \neq \mu 2$). The analysis provides a p-value that indicates the degree in which the data are different. A large p-value supports H_o, while a small p-value supports H_a. The level of significance, or the alpha level, selected was 0.05. If the p-value is less than 0.05, then H_a is accepted; if the p-value is greater than 0.05 than H_o is accepted. The level of significance is the maximum probability that chance or randomness produced the observed differences when, in fact, H_o is true

Regression Analysis

Regression Analysis

For further information refer to Chatterjee and Price (1991) or Frees (1995). Regression analysis is a process by which an attempt is made at fitting a mathematical model to a given set of data. Multiple independent variables are used to develop a relationship and predict the value of a dependent variable. Stepwise regression is a systematic way of adding or eliminating each independent variable in turn to formulate models to predict the dependent variable. The order that variables are added to the model does not reflect the importance of any particular variable

The procedure determines the relationship between the dependent variable and various independent variables. When the model includes all significant independent variables, meaning (1) all variables left in the model are significant at the agreed upon level of significance, 0.05 for this analysis, and (2) all pertinent variables are included in the judgement of the analyst, it is selected as the final model. Next, the diagnostic checks are completed. These checks include (1) a plot of the residuals to ensure that the data has no bias and (2) a plot of the actual and predicted values to verify the mathematical relationship.

For this regression analysis, labor efficiency was found to be the dependent variable. Labor efficiency for the model is expressed as DELTA%TOT which is delta divided by total actual labor hours taken as a percentage. Some of the independent variables used in the regression are:

(1) Amount of change as a percentage of total labor hours (ESTCHNG%TOT)

(2) Impact of change (IMP)

(3) Time of change (WTIMING)

(4) Experience of project management staff (EXP)

Other possible independent variables exist in the data, for example type of work and labor cost. However, they are not included in this thesis simply because they were not statistically significant in the prediction of labor efficiency.

Each of these variables was used in attempting to determine a relationship with labor efficiency. A correlation coefficient matrix was established to relate each of the independent variables to each other. The closer the value is to the absolute value of 1.0000, the more correlated the variables are. Correlation values were found to be small. As a result, no positive correlation between independent variables was established. Hence, all of the listed independent variables could be considered in our regression model.

The dependent variable chosen is Delta as a percent of total actual hours (DELTA%TOT). Stepwise regression was used to develop a model to predict DELTA%TOT as shown in Table B.1. Statistical Analysis System (SAS) was the computer software used.

Table B-1 - Stepwise Regression Method

Step (1)	Independent Variable Entered (2)	Independent Variable Removed (3)	# Variables in Model (4)	Partial R-Squared (5)	Model R-Squared (6)	Level of Significance (Probability > F) (7)
1	WTIMING		1	0.1563	0.1563	0.0087
2	EXPERIENCE		2	0.0820	0.2382	0.0445
3	WTIMING(UNIMP)		3	0.0590	0.2972	0.0781
4	IMPACT(OTHER)		4	0.1378	0.4350	0.0042
5		EXPERIENCE	3	0.0096	0.4254	0.4277
6	ESTCHG%TOT		4	0.0903	0.5157	0.0113

Column (5) contains the partial R^2 value. This partial coefficient of determination is the proportion of variability explained by the independent variable in the model. Column (6) contains the model R^2 values. These values are the proportion of variability explained by the entire regression model when containing all of the independent variables used to that point in the model. Column (7) shows the level of significance of each variable at that point in the model. The level of significance is based on the F distribution function and gives the probability that a given value is greater than F. No other independent variables were chosen to predict DELTA%TOT because they did not meet the 0.05 level of significance for entry into the model. EXPERIENCE was removed from the model because its level of significance of 0.4277, after adding the other independent variables, did not meet the 0.05 level of significance.

The definitions of each independent variable used in the final regression model are:

(1) WTIMING - denotes the timing of the change for all projects as explained in section 4.2.4.

(2) EXPERIENCE - indicates the project manager's experience using number of years with the company.

(3) WTIMING(UNIMP) - denotes the adjustment factor that must be added to WTIMING for unimpacted projects.

(4) IMPACT(OTHER) - is the adjustment factor that must be added to the intercept for projects impacted by items other than change.

(5) ESTCHG%TOT - is the total estimated change order hours divided by total actual labor hours and taken as a percentage.

This final stepwise regression produced the results found in Tables B.2 and B.3.

Table B.2 - Final Regression Model Values

Source (1)	Degrees of Freedom (2)	Sum of Squares (3)	Mean Square (4)	F Value (5)	Probability > F (6)
Model	4	5,437.17	1359.29	10.12	0.0001
Error	38	5,105.42	134.35		
Corrected Total	42	10,542.59			

Column (3), sum of squares, describes the total variation between the actual value and the value as calculated by the model. This variation is squared to eliminate the negative values

and the values are then summed to get the total variation. The mean square values, column (4), is the sum of the squares divided by the degrees of freedom. It is important that the model mean square be much larger than the error mean square. If not, the probability that the predicted regression line is incorrect increases.

Table B.3 - Final Regression Variable Values

Variable (1)	Parameter Estimate (2)	Degrees of Freedom (3)	Sum of Squares (4)	Mean Square (5)	F Value (6)	Probability > F (7)
Intercept	-21.3454				4.42	0.0421
WTIMING	8.8049	1	1,963.91	1,963.91	14.62	0.0005
WTIMING(UNIMP)	-5.0260	1	3,045.39	3,045.39	22.67	0.0001
ESTCHG%TOT	-0.2812	1	952.33	952.33	7.09	0.0113
IMPACT(OTHER)	23.2569	1	1832.87	1832.87	13.64	0.0007

The selected models, based on the parameter estimates in Table 4.8, are:

For impacted projects,

$$\textbf{DELTA\%TOT = -21.3 - 0.3(ESTCHG\%TOT) + 8.8(WTIMING)} \qquad \textbf{(B.1)}$$

And for unimpacted projects,

$$\textbf{DELTA\%TOT = -21.3 - 0.3(ESTCHG\%TOT) + 3.8(WTIMING)} \qquad \textbf{(B.2)}$$

The model has two similar equations with the difference being whether or not the project was impacted by change. The model has an R-squared value of 0.517 and an adjusted R-squared value of 0.4648. The R-squared value indicates the amount variability that is explained by the independent variables provided in the model.

Diagnostic Checking

Diagnostic checking was used to determine if there was bias in the model. As stated earlier, these checks include (1) a plot of the residuals to ensure that the data has no bias and (2) a plot of the actual and predicted values to verify the mathematical relationship. A residual is the difference between a data point and its predicted value. Figure B.1 shows the predicted value of delta versus the residuals.

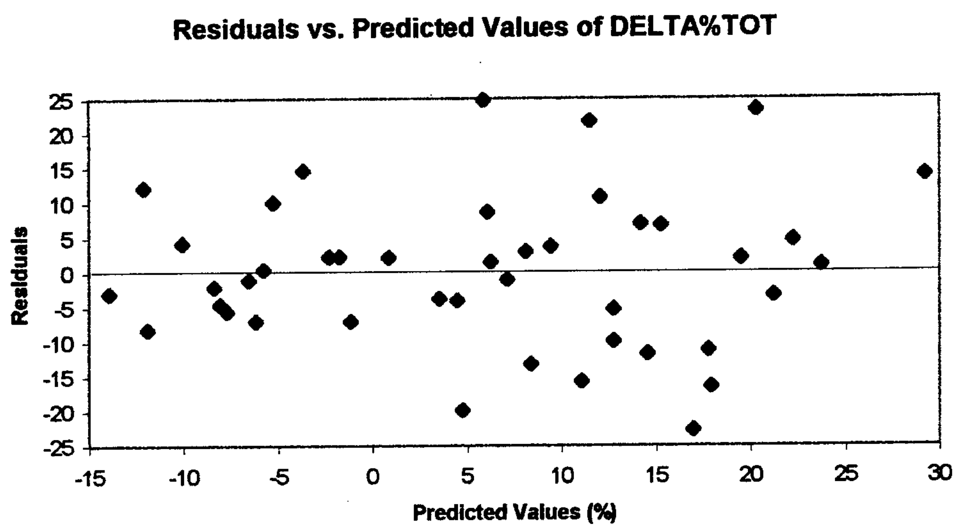


Figure B.1 - Residuals vs. Predicted Values

This plot shows that the residual values are random. Thus, it appears that the model is not biased. Figure B.2 shows the original delta values as given by contractors plotted versus the predicted delta value as given by the model. In this case, the data indicate a linear relationship as was expected.

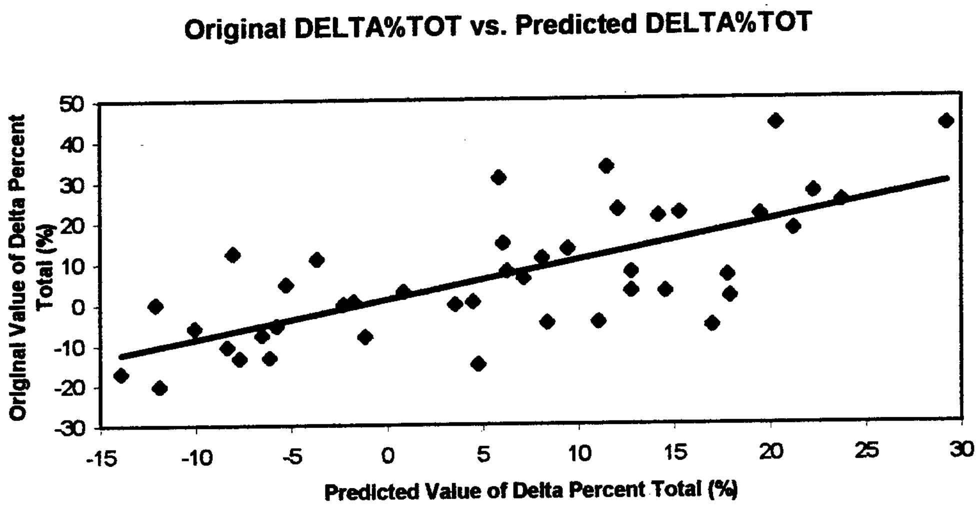


Figure B.2 - Model Predicted Value vs. Original Value

More project data should be collected to validate the regression model.

APPENDIX C: MODEL VERIFICATION DATA COLLECTION TOOL

Change Order Project Information Sheet

In order to validate our research model, we hope to attain information on a few more mechanical construction projects. Please fill this information sheet out twice, if possible. Once for a project impacted by change and once for a project unimpacted by change. Choose projects with good initial estimates that were contracted for lump sum payment.

1. Company Name ______________________________
2. Project Name ______________________________
3. Project Location ______________________________
4. Year Construction was complete 19 ______ (year)
5. Job Characterization (circle one): Impacted by change Unimpacted by change.

Please answer the following questions as they pertain to the mechanical portion of the project.

6. The original estimated total labor hours for the job was ______________ Hours.
7. The completed actual total labor hours for the job was ______________ Hours.
8. Please indicate the number of change orders that occurred on this job. ____________ #.
9. The estimated labor hours for all change orders is ______________ Hours.
10. The actual labor hours for all change orders is (if known) ______________ Hours.
11. Please *approximate* the timing of the changes (measure in labor hours expended).

Project % Complete	**% of Change Orders that had Occurred**
Before start	______________ %
0 - 20%	______________ %
21 - 40%	______________ %
41 - 60%	______________ %
61 - 80%	______________ %
81 - 100%	______________ %

APPENDIX D: CHANGE ORDER TRACKING TOOL

(Daily Change Order Log adapted from Thomack 1996)

ABC Mechanical Contractors

Daily Change Order Labor Log

Project Name: ________________ Total workers on jobsite: ______________

Project Number: _______________

Change Order work performed today:

CO # (1)	Item # (2)	Labor Code (3)	Crew Size (4)	Total Man-hours (5)	Description of work performed (6)

Were we impacted in our efforts to complete the work? Yes ☐ No ☐

If yes, fill in the following:

CO #	CO Impact?		Labor Code	Base Labor Impact?		Impact Factor (check all that apply):
	Yes	No		Yes	No	
(7)	(8)	(9)	(10)	(11)	(12)	(13)
						☐ Crew Chemistry ☐ Worker Morale ☐ Unclear Direction ☐ Material Management ☐ Congested Conditions ☐ Fatigue ☐ Trade Stacking ☐ Overtime Work ☐ Inclement Weather ☐ Other: State above (6)
						☐ Crew Chemistry ☐ Worker Morale ☐ Unclear Direction ☐ Material Management ☐ Congested Conditions ☐ Fatigue ☐ Trade Stacking ☐ Overtime Work ☐ Inclement Weather ☐ Other: State above (6)
						☐ Crew Chemistry ☐ Worker Morale ☐ Unclear Direction ☐ Material Management ☐ Congested Conditions ☐ Fatigue ☐ Trade Stacking ☐ Overtime Work ☐ Inclement Weather ☐ Other: State above (6)

____
Supervisor/Foreman Signature

Date

ABC Mechanical Contractors

Monthly Change Order Summary

Project Name: ____________________ Month: __________ Year: __________

Project Number: ____________

CO # (1)	Item # (2)	Labor Code (3)	Man-hours this Month (4)	Impact Factors (5)		Other Impact Factors (6)
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	

Project Manager: ____________________ Project Supervisor: ____________________

ABC Mechanical Contractors

Project Change Order Summary

Project Name: ____________________ Month: __________ Year: __________

Project Number: ____________

CO # (1)	Item # (2)	Labor Code (3)	Total Man-hours (4)	Impact Factors (5)		Other Impact Factors (6)
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	
				☐ Crew Chemistry ☐ Unclear Direction ☐ Congested Conditions ☐ Trade Stacking ☐ Inclement Weather	☐ Worker Morale ☐ Material Management ☐ Fatigue ☐ Overtime Work	

Project Manager: ____________________ Project Supervisor: ____________________

APPENDIX E: CHANGE ORDER LABOR IMPACT FACTOR CHECKLIST

Compiled from four references: *Change Orders, Overtime, Productivity*, MCAA 1994, *Changes,* SMACNA 1989, Kirksey Esq. 1994, and *Modification Impact Evaluation Guide,* United States Army 1979

Checklist of Possible Impacts on Labor Efficiency

Management Factors

- ☐ Ripple Effect to other Trades
- ☐ Management Non-Availability
- ☐ Dilution of Supervision
- ☐ Increased Project Administration
- ☐ Increased Need for Communication
- ☐ More Meetings
- ☐ Re-Engineering Time
- ☐ Increased Errors and Omissions
- ☐ Obsolete Plans and Specifications

Material Factors

- ☐ Material Expediting Delays
- ☐ Material Non-Availability

Equipment Factors

- ☐ Equipment Non-availability
- ☐ Tool Availability
- ☐ Unusual Scaffolding Requirements

Crew Factors

- ☐ Overtime
- ☐ Shiftwork
- ☐ Crew Fatigue
- ☐ Crew Morale
- ☐ Labor Non-Availability
- ☐ Crew Make-Up
- ☐ Reassignment of Manpower
- ☐ Unbalanced Crews
- ☐ Excessive Fluctuation in Manpower
- ☐ Learning Curve Loss
- ☐ Stop and Go Operations
- ☐ Working out of Normal Sequence
- ☐ Loss of Job Rhythm and Momentum
- ☐ Acceleration

Work Space Factors

- ☐ Crew Congestion
- ☐ Trade Stacking
- ☐ Weather Change
- ☐ Site Access
- ☐ Beneficial Occupancy
- ☐ Joint Occupancy
- ☐ Protection of Finished Work
- ☐ Poorly Accessible Work Areas
- ☐ More Hazardous Surroundings

APPROVED

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